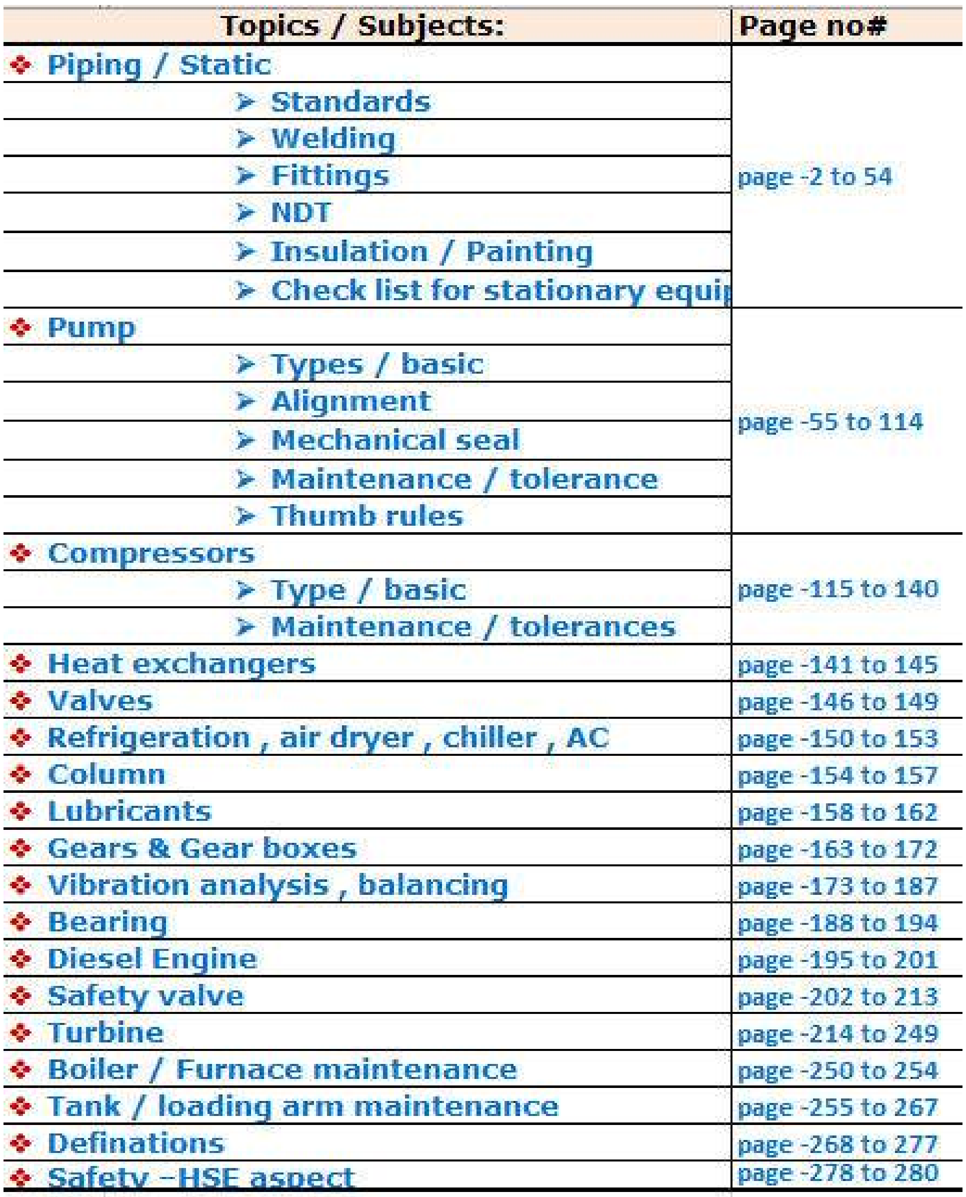
# Mechanical Maintenance-Rotating/static equipment's



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**Greetings to all,**

**This PDF (Mechanical Maintenance-Rotating/Static equipment's) ready for day to day mechanical maintenance job and for interview purpose (refer many books and taken photos/drawings), if you found its worth than its my humble request to give food to at least 02 needy people and spread this PDF file as you can.**

**With respect & regards**.

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## Static / Piping

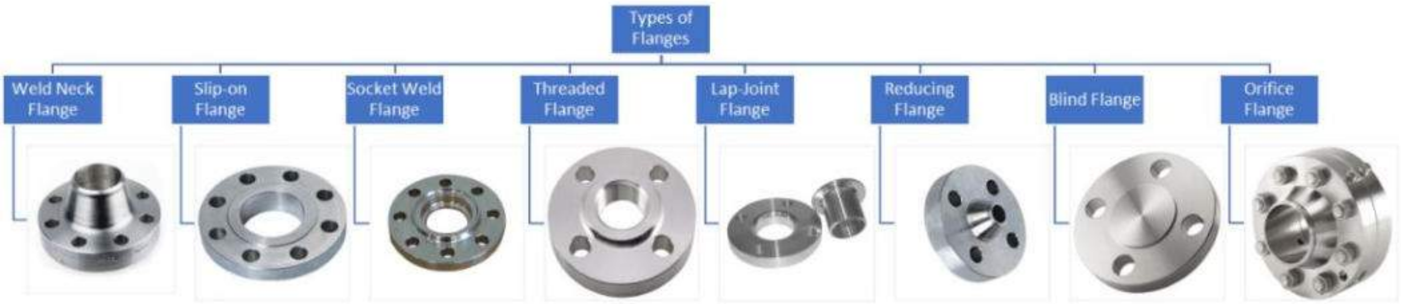
- **Which American institute standard does piping engineer refer?**
    - The American Petroleum institute (API).
    - The American Iron & Steel institute (AISI).
    - The American Society for Testing and materials (ASTM).
    - The American National standard institute (ANSI).
    - The American welding society (AWS).
    - The American Water Works Association (AWWA).
    - The American Society for Mechanical Engineers (ASME).

    ✓ **ASTM standards** deals with material grading/properties / tests and specify them.
    ✓ **ASME standards** deals with mechanical engineering subjects and specify / recommend standard practices.
- **What is the different ASME 31 code for pressure piping?**
- ASME B31.1 - Power piping.
- ASME B31.2 - Fuel Gas Piping.
- ASME B31.3 - Process piping.
- ASME B31.4 - Pipeline Transportation system for liquid hydrocarbon & other liquid.
- ASME B31.5 - Refrigeration Piping.
- ASME B31.8 - Gas transmission & distribution piping system.
- ASME B31.9 - Building services piping.
- ASME B31.11 -Slurry transportation piping system.

**Applicable ASME Standards for Flanges / Fittings**

- ASME B16.1 - Cast Iron Pipe Flanges and Flanged Fittings
- ASME B16.5 - Pipe Flanges and Flanged Fittings
- ASME B16.24 - Cast Copper Alloy Pipe Flanges & Flanged Fittings
- ASME B16.36 - Orifice Flanges
- ASME B16.42 - Ductile Iron Pipe Flanges and Flanged Fittings: Classes 150 and 300
- ASME B16.47 - Large Diameter Steel Flanges: NPS 26 through NPS 60 Metric/Inch Standard

- **How can flanges be classified based on Pipe Attachment?**
    - **Slip on**. : The Slip-on type flanges are attached by welding inside as well as outside. These flanges are of forged construction.
    - **Socket Weld**. : The Socket Weld flanges are welded on one side only. These are used for small bore lines only.
    - **Screwed.** : The Screwed-on flanges are used on pipe lines where welding cannot be carried out.
    - **Lap Joint.** : The Lap Joint flanges are used with stub ends. The stub ends are welded with pipes & flanges are kept loose over the same.
    - **Weld Neck**. : The Welding neck flanges are attached by butt welding to the pipe. These are used mainly for critical services where the weld joints need NDT inspection.
    - **Blind.** : The Blind flanges are used to close the ends which need to be reopened.



- Flanges are classified based on pressure / temperature ratings as: -
  A. 150 # B. 300 # C. 400 # D. 600 # E. 900 # F. 1500 # G. 2500 #
- Flanges are classified based on facing as: A. Flat face. (FF) B. Raised face. (R/F) C. Tongue and groove. (T/G) D. Male and female. (M/F) E. Ring type joint. (RTJ)
- Based on face finish as: A. Smooth finish. B. Serrated finish.

**Common API (American Petroleum Institute) piping materials are:**

- API 5L : Carbon Steel Seamless pipe
- API 5LX 46 : Carbon steel seamless pipe with specified Minimum Yield Strength of 46,000 psi (316.5 MPa)

**Designations and Descriptions of Common ASTM Piping Materials:** Most components of piping systems are constructed from carbon steels and alloy steels such as stainless steels. Common ASTM designations and descriptions of pipe materials are given here.

- ASTM A106 Gr.B: Carbon steel seamless pipe (most commonly used material for pipe)
- ASTM A53 Gr.B: Carbon steel seamless or Electric Resistance Welded (ERW) pipe.
- ASTM A333 Gr.6: Low and Intermediate Alloy Steel pipe
- ASTM A312 TP304: Seamless Stainless Steel pipe.

**Common ASTM Designations of Flanges, Pipe Fittings and valves:**

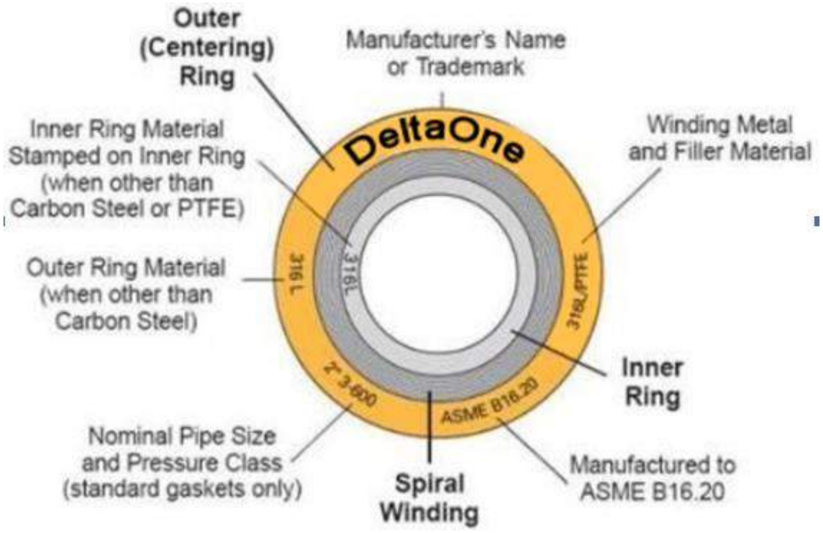
- ASTM A 105: Carbon steel flanges and forged fittings
- ASTM A 182: Alloy Steel (for example stainless steel) flanges, fittings and valves for high temperature service
- ASTM A 126: Gray Cast Iron Castings for Valves, Flanges and Pipe Fittings
- ASTM A 351: Austenitic Steel Casting for High Temperature Service
- ASTM A 350 Gr. LF 2: Carbon Steel/Low Alloy Steel forgings for piping components.

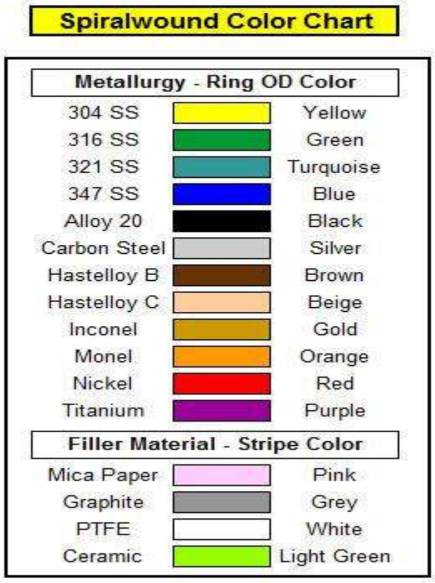
- **Where the smooth finish flange & serrated finish flange use?**
  The smooth finish flange is provided when metallic gasket is provided and serrated finish flange is provided when non-metallic gasket is provided.

- **What are the types of serrated finish provided on flange face?**
  **A.** Concentric or **B.** Spiral (Phonographic).

- **How the serration on flanges is specified?**
  The serration on flanges is specified by the number, which is the **Arithmetic Average Rough Height (AARH).**

- **What is centering / outer ring in spiral wound gasket?**
  (Below example.)Spiral wound gaskets are provided with carbon steel external ring called centering ring.


Outer (Centering) Ring
Manufacturer's Name or Trademark
Inner Ring Material Stamped on Inner Ring (when other than Carbon Steel or PTFE)
Winding Metal and Filler Material
DeltaOne
316L
316L
316L/PTFE
Outer Ring Material (when other than Carbon Steel)
2" 3-600
ASME B16.20
Inner Ring
Nominal Pipe Size and Pressure Class (standard gaskets only)
Spiral Winding
Manufactured to ASME B16.20

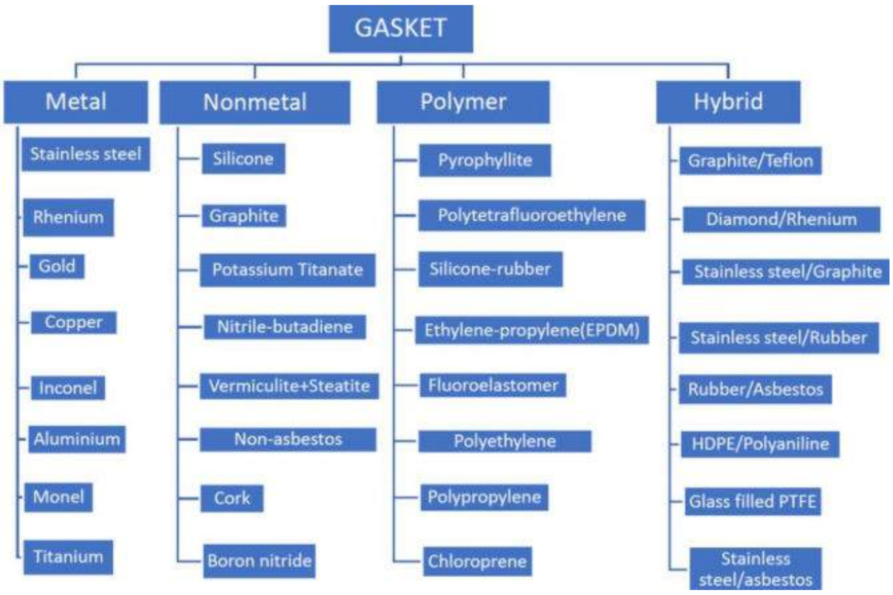


**Spiralwound Color Chart**

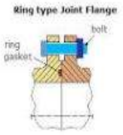
| Metallurgy - Ring OD Color | | |
|---|---|---|
| 304 SS | 🟨 | Yellow |
| 316 SS | 🟩 | Green |
| 321 SS | 🟦 | Turquoise |
| 347 SS | 🟦 | Blue |
| Alloy 20 | ⬛ | Black |
| Carbon Steel | ⬜ | Silver |
| Hastelloy B | 🟫 | Brown |
| Hastelloy C | 🟧 | Beige |
| Inconel | 🟨 | Gold |
| Monel | 🟧 | Orange |
| Nickel | 🟥 | Red |
| Titanium | 🟪 | Purple |
| **Filler Material - Stripe Color** | | |
| Mica Paper | 🟪 | Pink |
| Graphite | ⬜ | Grey |
| PTFE | ⬜ | White |
| Ceramic | 🟩 | Light Green |

**GASKET MATERIAL / USE :**

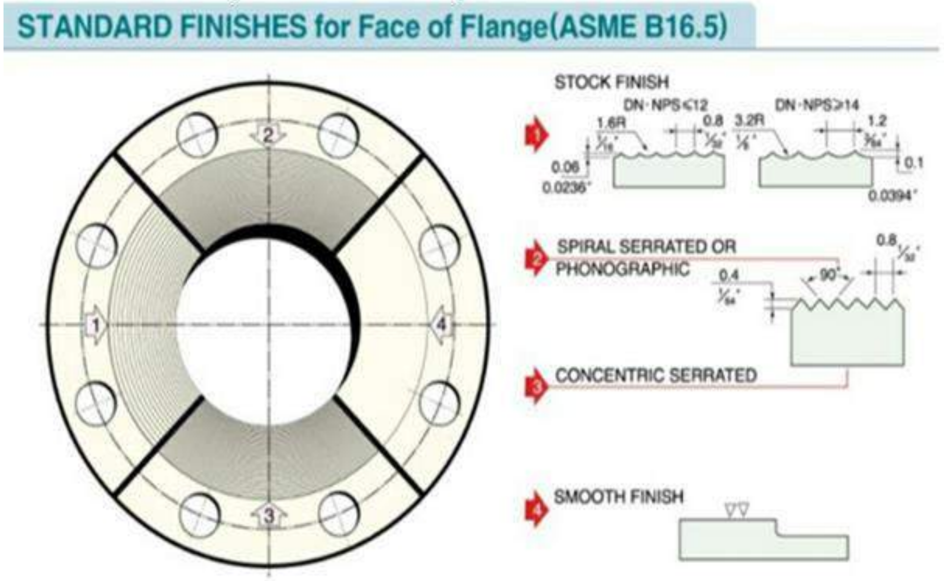
| GASKET MATERIAL | EXAMPLE USE | MAX. TEMP. DEG.F/C |
|---|---|---|
| Synthetic rubbers | Water, Air | 250/120 |
| Vegetables Fiber | Oil | 250/120 |
| Solid Teflon | Chemicals | 500/240 |
| Compressed Asbestos | Most | 750/400 |
| Carbon Steel | High Pressure Fluid | 750/400 |
| Stainless Steel | HP. Fluid / Corrosive | 1200/650 |
| Teflon | Most | 750/400 |
| CS / Asbestos | Corrosive | 1200/650 |
| SS / Asbestos | Chemicals | 500/240 |
| SS / Ceramics | Hot Gases | 1900/1050 |


GASKET
Metal
Stainless steel
Rhenium
Gold
Copper
Inconel
Aluminium
Monel
Titanium
Nonmetal
Silicone
Graphite
Potassium Titanate
Nitrile-butadiene
Vermiculite+Steatite
Non-asbestos
Cork
Boron nitride
Polymer
Pyrophyllite
Polytetrafluoroethylene
Silicone-rubber
Ethylene-propylene(EPDM)
Fluoroelastomer
Polyethylene
Polypropylene
Chloroprene
Hybrid
Graphite/Teflon
Diamond/Rhenium
Stainless steel/Graphite
Stainless steel/Rubber
Rubber/Asbestos
HDPE/Polyaniline
Glass filled PTFE
Stainless steel/asbestos

- **RING JOINT FACING (RTJ):**
  Most efficient for high temperature and high pressure service. Ring joint facing is not prone to damage in handling as the surfaces in contact with the gasket are recessed. Use of facing of this type may increase as hollow metal O- ring gain acceptance for process chemical seals.


Ring type Joint Flange
bolt
ring
gasket

- **TYPES OF FINISH ( FLANGE RAISED FACE ) ARE :**
  a) Serrated b) smooth c) stock finish


STANDARD FINISHES for Face of Flange(ASME B16.5)
1
2
3
4
STOCK FINISH
DN·NPS≤12
DN·NPS≥14
1.6R
1/16"
0.8
1/32"
3.2R
1/8"
1.2
3/64"
0.06
0.0236"
0.1
0.0394"
SPIRAL SERRATED OR PHONOGRAPHIC
0.4
1/64"
90°
0.8
1/32"
CONCENTRIC SERRATED
SMOOTH FINISH

**Types of gasket:**

CNAF FULL FACE GASKET 3" 300#

This a CNAF (Compresses non-asbestos fibre) Full Face Gasket.

CNAF RF GASKET 3" 300#

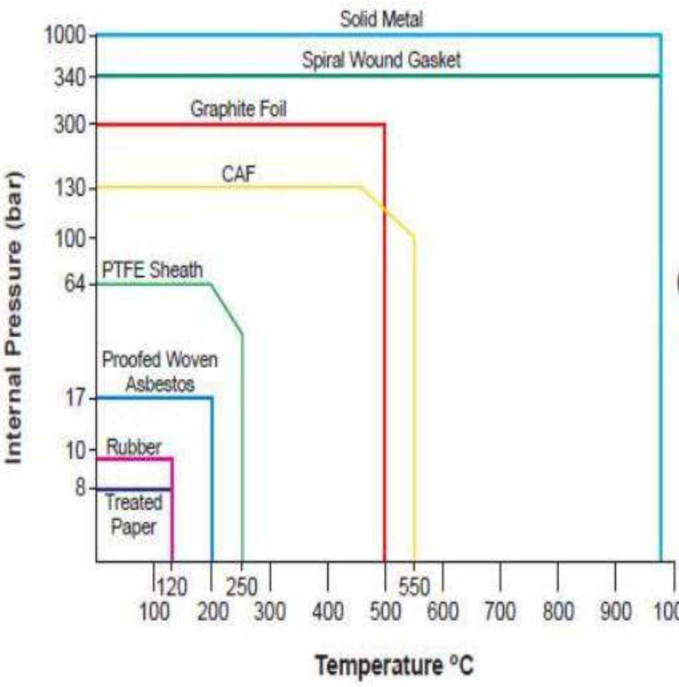
This a CNAF (Compresses non-asbestos fibre) Raised Face Gasket.

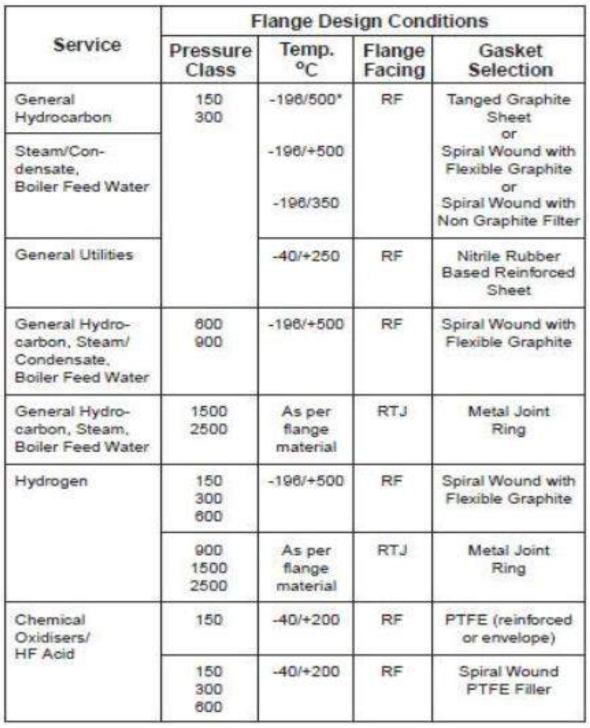
SPIRAL WOUND 3" 300# NEW

Spiral wound gasket. Used with Raised Face Flanges. Composite of wound metal and a filler.

TANGED GRAPHITE 4" 150#

Commonly used as a gasket material in steam system applications. Includes one or more insertions of tanged 0.10mm thick stainless steel.





| Service | Flange Design Conditions | | | |
|---|---|---|---|---|
| | Pressure Class | Temp. °C | Flange Facing | Gasket Selection |
| General Hydrocarbon | 150<br>300 | -196/500* | RF | Tanged Graphite Sheet or Spiral Wound with Flexible Graphite or Spiral Wound with Non Graphite Filter |
| Steam/Condensate, Boiler Feed Water | | -196/+500<br>-196/350 | | |
| General Utilities | | -40/+250 | RF | Nitrile Rubber Based Reinforced Sheet |
| General Hydrocarbon, Steam/ Condensate, Boiler Feed Water | 600<br>900 | -196/+500 | RF | Spiral Wound with Flexible Graphite |
| General Hydrocarbon, Steam, Boiler Feed Water | 1500<br>2500 | As per flange material | RTJ | Metal Joint Ring |
| Hydrogen | 150<br>300<br>600 | -196/+500 | RF | Spiral Wound with Flexible Graphite |
| | 900<br>1500<br>2500 | As per flange material | RTJ | Metal Joint Ring |
| Chemical Oxidisers/ HF Acid | 150 | -40/+200 | RF | PTFE (reinforced or envelope) |
| | 150<br>300<br>600 | -40/+200 | RF | Spiral Wound PTFE Filler |

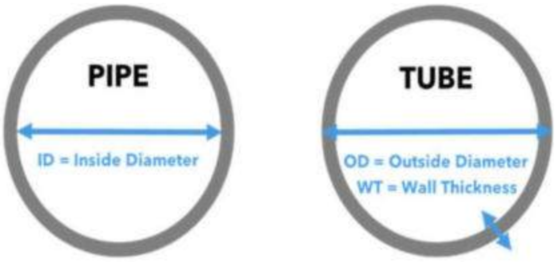
- **What are the criteria for selection of MOC of Spiral Wound metallic Gasket winding material?**

  The selection of material of construction for Gasket winding depends upon: -
  - The corrosive nature and concentration of fluid being carried.
  - The operating pressure & temperature of the fluid.
  - The relative cost of alternate winding material.
- **Main parts of Spiral wound Gasket:** Outer Ring (center ring), winding material with Filler (spiral winding), Inner Ring.
- **What are the most common materials used for spiral wound metallic gasket spiral winding?** Austenitic stainless steel with asbestos / graphite / Teflon filler.
- **Which material is used as filler material for spiral wound gasket in case of high temperature services?** Graphite filler is used.
- **Up to what temperature limits the low strength carbon steel bolts should be used for flanged joints?** Shall be used between -28C to 200C
- **Up to what temperature the carbon steel materials shall be used?** Up to 425C.
- **Which material is used for temperature above 426C?** Alloy steel materials shall be used.
- **Which type of material is used for corrosive fluid?** Stainless steel materials shall be used
- **Which type of piping materials are used for utility -drinking water, instrument air etc?**

  Galvanized steel materials shall be used for drinking water, instrument air and N2 lines.
- **What is the difference between Pipe and Tube?**

  Pipe is identified by NB (ID-NB nominal bore) and thickness is defined by Schedule whereas Tube is identified by OD & its thickness as BWG (Birmingham wire gauge or 1/100 inch),

  ✓ In pipe OD is standard and in tube ID is standard.



- **What should be the radius of long radius elbow?**

  1.5D (Where "D" is the diameter of the pipe.)- Long radius elbow are used for small pressure drop
- **What should be the radius of short radius elbow?**

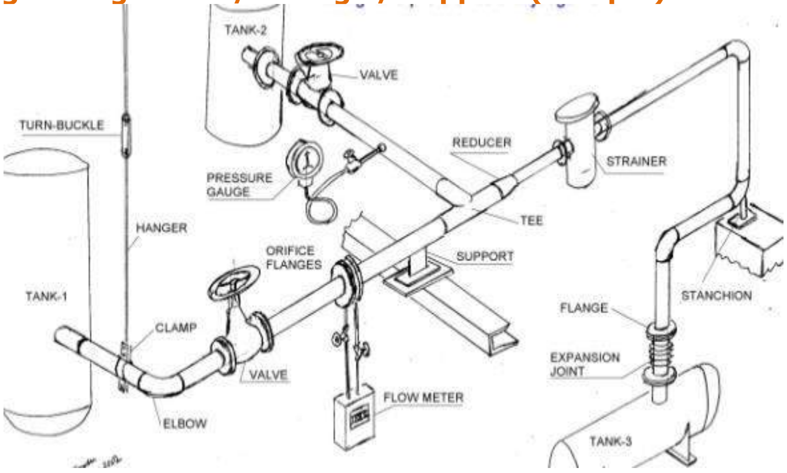
  1D (Where "D" is the diameter of the pipe.)- short radius elbow are used for high pressure drops
- **How the pipe fittings are classified based on end connections?**

  Pipe fittings are classified based on end connection as: -

  **A.** Socket welds fittings. **B.** Screwed/thread end fittings. **C.** Beveled end or Butt weld fittings' **D.** flange end fittings. Etc…
- **How the valves are classified based on end connection?**

  End connection means arrangement of attachment of the valve with the equipment or the piping.

  **A.** Screwed ends. **B.** Socket ends. **C.** Flanged ends. **D.** Butt weld ends.
  **E.** Wafer type ends. **F.** Buttress ends.
- **Piping arrangement / fittings / support (exmple):**

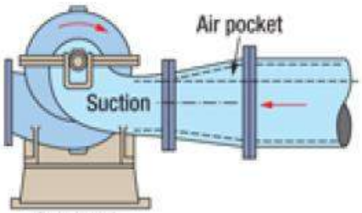


- **Normally where do we use the following reducers?**

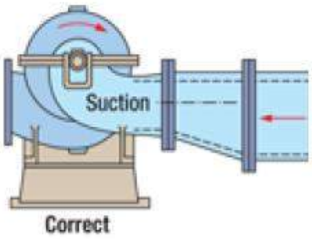
  **A. Eccentric reducers. B. Concentric reducers.**

  **A.** Eccentric reducers = Air pockets may form if concentric reducer is used at pump suction, which results in cavitation and cause damage to Pump. To avoid this problem, Eccentric Reducer with flat side up (FSU) is used in Pump Suction.

  **B.** Concentric reducers = Pump discharge, vertical pipeline etc.



Incorrect



Correct

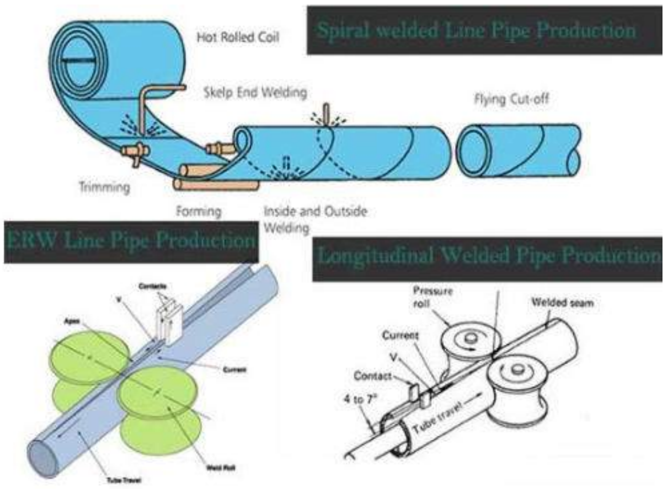
Concentric Reducer

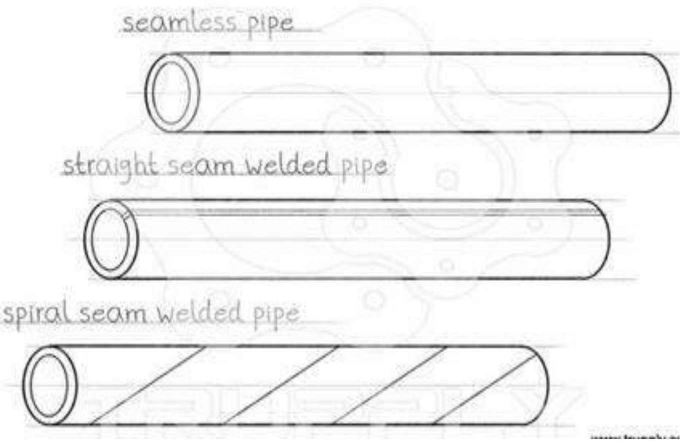
Eccentric Reducer

- **Difference between Codes, Standards and Specifications?**
    - Code is procedure of acceptance and rejection criteria.
    - Standard is accepted values and compare other with it.
    - Specification is describing properties of any type of materials

- **Where the ERW spiral, longitudinal & seamless pipes are used?**

Use depends upon the availability of pipes. Nothing functional difference between ERW & Longitudinal pipe. Normally, above 18” ERW pipes are used & Below 18” seamless pipes are used. Seamless pipes can sustain higher temperature & pressure.


Spiral welded Line Pipe Production
Hot Rolled Coil
Skelp End Welding
Flying Cut-off
Trimming
Forming
Inside and Outside Welding
ERW Line Pipe Production
Longitudinal Welded Pipe Production
Pressure roll
Welded seam
Current
V
Contact
4 to 7°
Tube travel


seamless pipe
straight seam welded pipe
spiral seam welded pipe

**Electric Resistance Weld (ERW) Pipe:** Pipe having one longitudinal seam formed by electric resistance welding (ERW) or electric induction welding without the addition of extraneous (filler) metal

**Seamless Pipe:** A wrought steel tubular product made without a welded seam. It is manufactured by hot working steel, or if necessary, by subsequently cold finishing the hot-worked tubular product to produce the desired shape, dimensions and properties

- **From which side of pipe will you take a branch connection?**

**When fluid is Gas, Air or Steam and Cryogenic Service** – Topside.

**In Cryogenic Service -** There is the chance of ice formation during normal operation and since ice flows from the bottom of the pipe it will block/restrict the branch pipe connection.

**When Fluid is Liquid** – Bottom Side.

- **Why do we provide High Point Vent (HPV) and Low Point Drain (LPD) in piping?**

HPV –For removing Air during Hydro-test. &
LPD – For draining water after conducting Hydro-test.

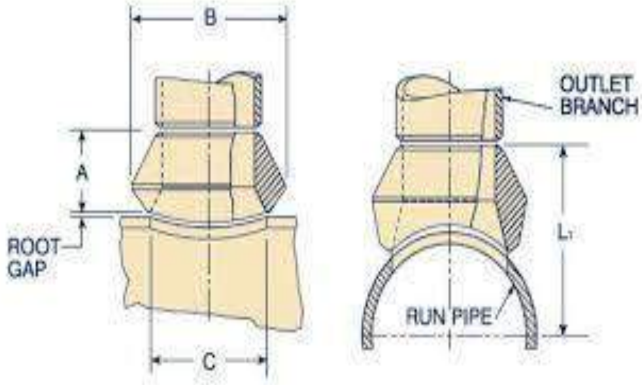
- **What do you mean by Jacketed Piping?**

for uniform application of heat to the process, as well as maintaining the most uniform processing temperatures where steam tracing is not capable of maintaining the temperature of fluid constant. Usually used for molten Sulphur, Polymers service.

- **What is the minimum distance to be maintained between two welds in a pipe?**

The thumb rule is that the minimum distance between adjacent butt welds is 1D. If not, it is never closer than 1-1/2". This is supposedly to prevent the overlap of HAZs. Minimum spacing of circumferential welds between centerlines shall not be less than 4 times the pipe wall thickness or 25 mm whichever is greater.

- **What are Weldolet and Sockolet? and where they are used?**
    - Weldolets and sockolets are self-reinforced fittings.
    - Weldolets are used for butt welded branch connections where standard tee is not available due to size restrictions and the piping is at a critical/high pressure service.
- Sockolets are used to socket welding branch connection


B
A
ROOT GAP
C
OUTLET BRANCH
L
RUN PIPE

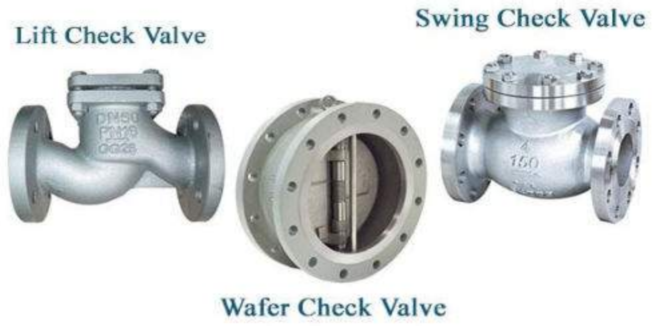
**Weldolet**

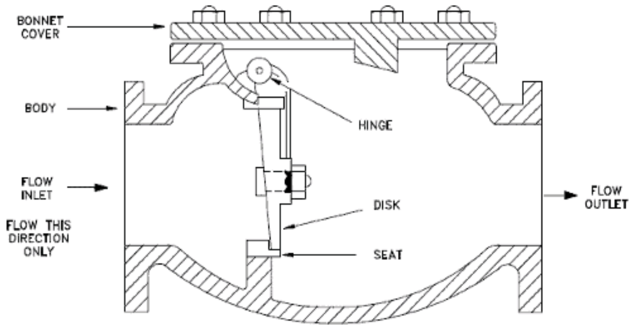
**Sockolet fittings**

- **What are the things to be checked in socklets?**
    - All fitting bores are to be concentric within 0.76mm for all sizes.

  - To prevent cracking of a fillet weld install a 1.5 cardboard washer or withdraw the pipe 1.5 mm from bottom of the socket before welding.

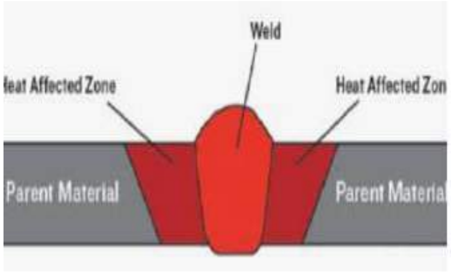
- **What are the types of check valves (NRV-non-return valve)?**
  Check valves are divided into two types based on check mechanism as: -
  **A.** Lift check valve. **B.** Swing check valve.


Lift Check Valve
Swing Check Valve
Wafer Check Valve

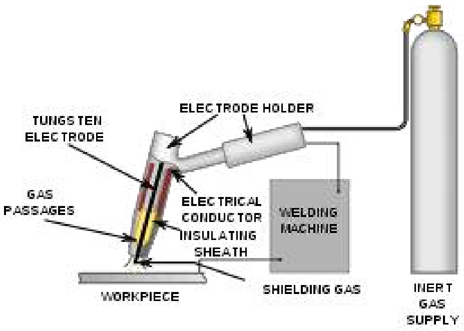

BONNET COVER
BODY
FLOW INLET
FLOW THIS DIRECTION ONLY
HINGE
DISK
SEAT
FLOW OUTLET

- **What do you mean by special purpose valves?** Valves that perform duties other than the two-way isolation, control and check are called special purpose valves.
- **What is mean by 'PWHT'? Why it is required?** "POST WELD HEAT TREATMENT" This is done to remove residual stress left in the joint which may cause brittle fracture. To maintain uniform homogeneous structure / piping.

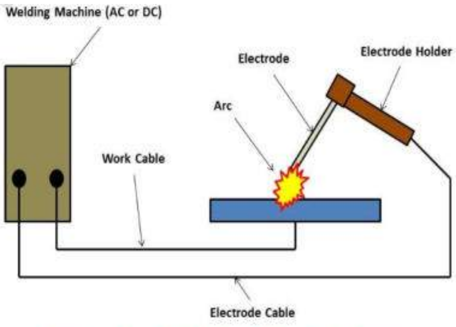
Pre Heating and Post Weld Heat Treatment (PWHT):


Weld
leat Affected Zone
Heat Affected Zon
Parent Material
Parent Materia

- **What should be the content of chlorine in water while conducting hydro test for CS & SS pipes?** For CS – 250 PPM & For SS – 30 PPM.—chlorine content in water (refer API 570).
- **What is the affect if the quantity of hydrogen induced in weld metal is more?**
  When hydrogen is more in weld metal; it tends to make the material brittle & subsequently leads to cracking. These cracks are called hydrogen induced cracking or delayed crack. To avoid this the electrode before using is backed at 250C to 300C for one hour in mother oven & then cooled down to 100C in the same oven & finally transferred to portable oven for use where temperature is maintained at 60C to 70C.
- **Mention the parts of TIG welding set?**
  A. Torch: Consist of hose for argon gas / welding lead / ceramic nozzle/ collet / tungsten rod as cathode to create arc.
  B. Regulator with Pressure Gauge (HP & LP) & flow meter.
  C. Argon cylinder – Gr.2 / Gr.1 depending upon requirements of the job.
  D. Transformer / Rectifier.
  E. Filler wire


TUNGSTEN ELECTRODE
ELECTRODE HOLDER
GAS PASSAGES
ELECTRICAL CONDUCTOR
INSULATING SHEATH
WELDING MACHINE
WORKPIECE
SHIELDING GAS
INERT GAS SUPPLY

## Basic Arc WELDING CIRCUIT:


Welding Machine (AC or DC)
Electrode
Electrode Holder
Arc
Work Cable
Electrode Cable

Basic Arc Welding Circuit Diagram

- **What are the Criteria for Pipe Supporting?**

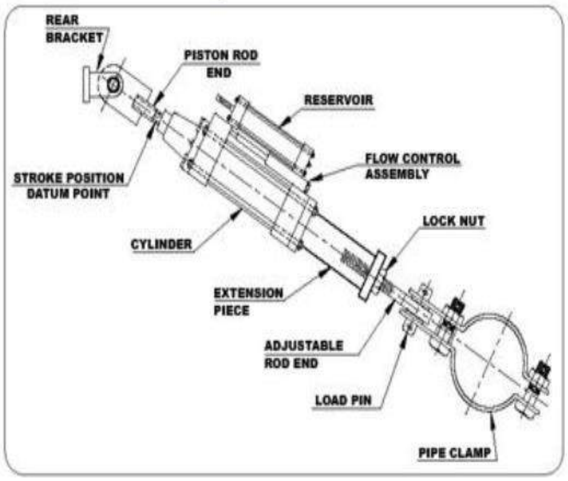
  Following are the points, which should be taken into account for proper supporting: -
  A. Load of bare pipe + fluid + insulation (if any).
  B. Load of bare pipe + water fills.
  C. Load of valves and online equipment and instrument.
  D. Thermal loads during operation.
  E. Steam out condition, water hammering / surge …etc..if applicable.
  F. Wind loads for piping at higher elevation, if required.
  G. Forced vibration due to pulsating flow.
  H. pipe support with Pad or Shoe.
  I. Pressure / temp. of pipeline

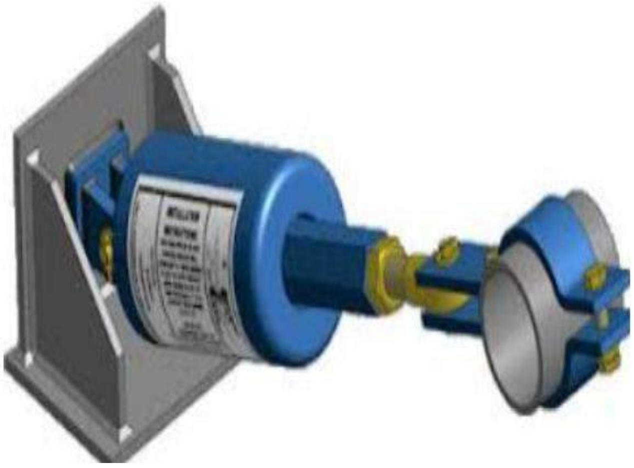
- **What is the purpose of providing Graphite Pads in pipe supports below shoes?**

  To reduce the friction. The co-efficient of friction for Graphite pads is 0.1

- **What are sway braces support in piping?**

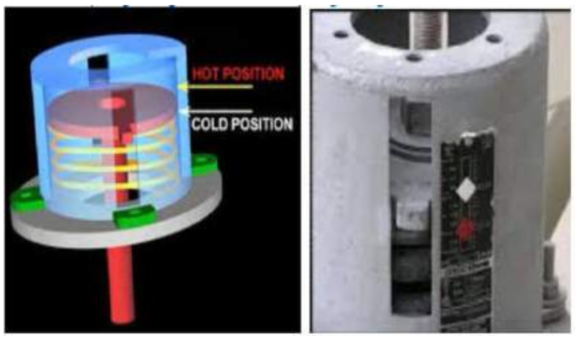
Sway braces are essentially a double acting spring housed in a canister. Their purpose is to limit the undesirable movement. Undesirable movement means movement caused by wind loading, rapid valve closure, relief valve opening, two phase flow or earthquake.





- **What is the difference between variable spring hanger and constant spring hanger?**

  **Variable spring Hanger**: -As the name itself indicates the resistance of the coil to a load changes during compression.



  **Constant spring Hanger**: - Constant spring hanger provides constant support force for pipes and equipment subjected to vertical movement due to thermal expansion.

- **What are the basic principles of locating the Equipment irrespective of the type of arrangement?**

  The certain basic principles to be followed while locating the equipment is as: -

  **A. Economic piping:**
  In order to minimize the cost of piping, the equipment should be located in process sequence and close enough to suit safety needs, access requirements and flexibility. The equipments are identified which forms the subsystem within the unit. The component within the subsystem to be arranged to have most economical piping and the whole subsystem to be arranged within the unit to have most economic interconnection.

  **B. Process Requirement:**
  The equipment layout should support requirement like minimum pressure drop, gravity feed and loop.

**C. Common operation:**
The equipment that requires common maintenance facilities, common utility and continues operator attention shall be located the same area.

**D. Underground Facilities:**
Before deciding the equipment location, the facilities such as storm water drain, effluent drain, fire water, cooling water to be placed underground.

- **Design of any processing plant is usually accomplished in three phases**
  a) **Conceptual Design** – are made when sketchy or minimal information is used to prepare an abstract arrangement of a plot plan or an equipment and piping layout.
  b) **Preliminary or study phase** – design are made with unchecked or uncertified data to design a facility in sufficient detail so that the document produced can be used for detail design.
  c) **Detail phase** – All design are finalized, the design used such checked data as steel and concrete, drawings, hydraulic and certified vendors drawings for equipment valves and instruments.

**What are the two basic configurations for the equipment layout (unit plot plan)?**
The equipment layout can basically be divided into two configurations:

**A. The Horizontal arrangement** as seen in the refineries and petrochemical plants. The equipment is placed on the either side of the central pipe rack with auxiliary roads. Advantage of this arrangement is that the equipment is located at grade level, which makes it easier to construct, operate and maintenance. Disadvantage is that it takes lot of ground area

**B. The vertical Arrangement** as seen in many chemical process industries.
The structure mounted vertical arrangement has equipment located at multilevel in steel or concrete structure. This could be indoor or outdoor. Advantage is of small coverage area and ability to house the facility to suit process requirement or climate conditions.

- **How much space is kept in between column of pipe rack?**
  Normally, 5 to 6 Mtrs. spacing is kept in between the column of pipe rack.
- **What are the factors upon which the mechanical properties of material are dependent?**
  **A.** Chemical composition of the material.
  **B.** Method by which the material is manufactured.
- **How much design temperature shall be considered for the insulation of structure, vessel parts , piping ?**
  The highest expected temperature/design temp. of the heating media plus 10-20C. Here, 10-20C is the safety margin. And for fired vessel parts which are shielded (by Refractory) 20C and the parts which are unshielded 50C
- **What are the types of failures encountered in Piping / structure?**

**1. Catastrophic Failure**. The failures which occurs suddenly as soon as the load crosses the threshold (Ultimate tensile strength). These failures take place on the first occurrence of the loads in excess of yield stress.

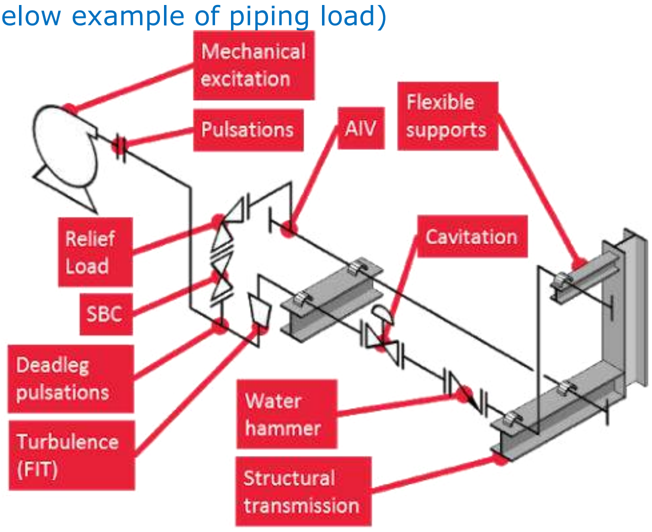
**2. Fatigue Failure.** The failure which occurs due to damaging of the grain structure of the specimen subjected to prolonged application of sustained load and or tensile –compressive load cycle.

Types of fatigue failure are:-

**A. Static Fatigue**: The specimen which fails under sustained load subjected to considerable length of time. The total time for which the load was applied is important. Whether it is applied continuously or in installments is not important.

**B. Cyclic Fatigue**: The specimen which fails under a load cycle subjected to considerable numbers of times. The total numbers of cycles for which the load was applied is important. Whether the cycle was frequent or infrequent is not important.

- **What are Primary, Secondary and Occasional Loads in piping?**
- **Primary** load occurs from Sustained loads like dead weight, live weight, internal pressure etc. and are called non-self-limiting loads.
- **Secondary** loads occur from thermal expansion loads like temperature change, anchors and restraints etc. and are called self-limiting loads.
- **Occasional** loads occur from static wind and seismic loads and are considered to act occasionally. (Below example of piping load)



## Objectives of Pipe Stress Analysis

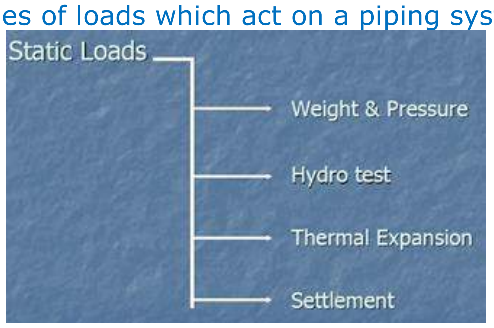
- **Structural Integrity:**
  - ✓ Design adequacy for the pressure / temp. of the carrying fluid.
  - ✓ Failure against various loading in the life cycle.
- **Operational Integrity:**
  - ✓ Limiting nozzle loads of the connected equipment within allowable values.
  - ✓ Avoiding leakage at joints.
  - ✓ Limiting sagging & displacement within allowable values.
- **Optimal Design:**
  - ✓ Avoiding excessive flexibility and also high loads on supporting structures. Purpose towards an optimal design for both piping and structure.

## Sources for the generation of stress in a Piping System:

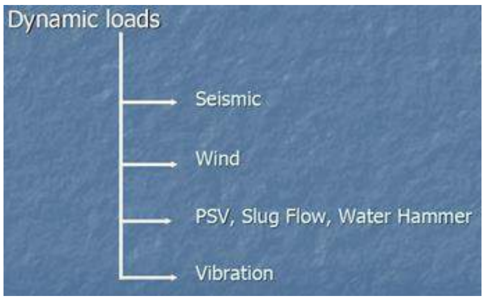
1. Weight
2. Internal/External Pressure
3. Temperature change
4. Occasional Loads due to the wind, seismic disturbances, PSV discharge, water hammering etc.
5. Forces due to Vibration.

## Loads on a Piping System

There are two types of loads which act on a piping system: Static loads and Dynamic Loads



Static loads are those loads that act very slowly and the system gets enough time to react against it.



On the other hand, dynamic loads act so quickly that the system does not get enough time to react against it.

- **What are the steps involved in stress analysis?**
  - ✓ Identify the potential loads that the piping system would encounter during the life of the plant.
  - ✓ Relate static / dynamic loads to the stresses and strains developed.
  - ✓ Get the cumulative effect of the potential loads in the system and to ensure that the stresses are within safe limits.
  - ✓ Pressure & temperature factor
  - ✓ Decide the allowable limits the system can withstand without failure as per code/standard.

- **What are the Inputs required for stress analysis of a piping system?**

  **A.** Pipe Size. **B.** Fluid Temperature. **C.** Pipe Material. **D.** Model. **E.** Design pressure. **F.** Insulation Thickness. **G.** fluid Specific gravity. **H.** Friction coefficient.

- **What is the normal desired life cycle for Piping in operation?**

  Desired life cycle for Piping in operation is 20 Years (7000 Cycles).

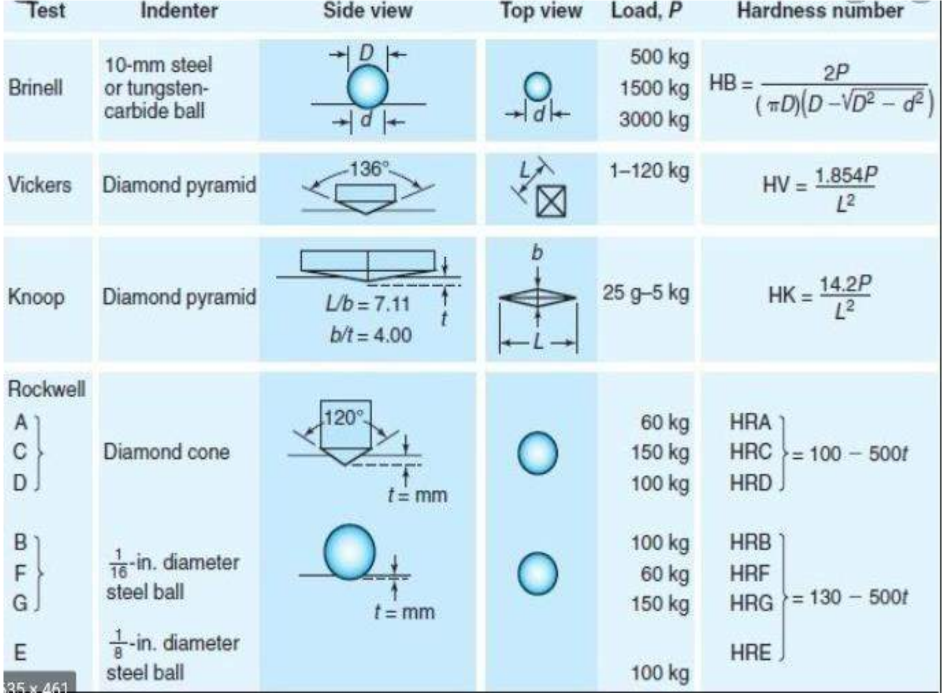
- **Which fluid is used in Heat Exchanger in shell side and tube side?**

  Generally corrosive fluid is used from the tube side (as tube can be easily replaced) and cleaner fluid is used from shell side. Sometimes Hot fluid is also used from the shell side.
- **What is cold type of wrapping?**

  PVC backed bituminous compound tape used for field wrapping is called cold wrapping.

- **What are the different types of hardness tests carried out?**

  Brinell hardness Test,Rockwell Hardness Test & Vickers Hardness Test.

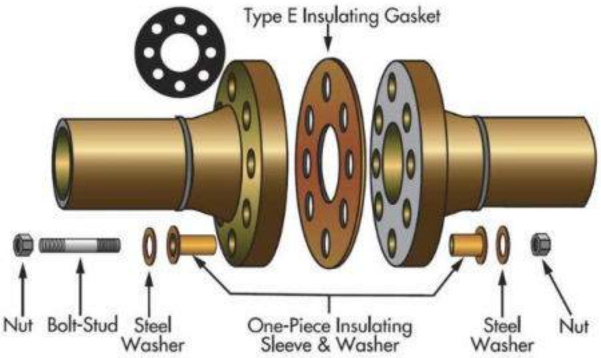


| Test | Indenter | Side view | Top view | Load, P | Hardness number |
|---|---|---|---|---|---|
| Brinell | 10-mm steel or tungsten-carbide ball | D<br>d | d | 500 kg<br>1500 kg<br>3000 kg | $HB = \frac{2P}{(\pi D)(D - \sqrt{D^2 - d^2})}$ |
| Vickers | Diamond pyramid | 136° | L | 1–120 kg | $HV = \frac{1.854P}{L^2}$ |
| Knoop | Diamond pyramid | $L/b = 7.11$<br>$b/t = 4.00$<br>t | b<br>L | 25 g–5 kg | $HK = \frac{14.2P}{L^2}$ |
| Rockwell<br>A<br>C<br>D | Diamond cone | 120°<br>t = mm | | 60 kg<br>150 kg<br>100 kg | HRA<br>HRC<br>HRD $= 100 - 500t$ |
| B<br>F<br>G | $\frac{1}{16}$-in. diameter steel ball | t = mm | | 100 kg<br>60 kg<br>150 kg | HRB<br>HRF<br>HRG $= 130 - 500t$ |
| E | $\frac{1}{8}$-in. diameter steel ball | | | 100 kg | HRE |

- **What are Insulating Gasket Kits?**

  Insulation gasket kits are designed to restrict the effects of corrosion often found in flanged pipe systems (underground / above ground). The most common example is fire water line running inside the ground and turned upward on above ground with flanged connection.

  It consists of following kits: -



**A.** Gasket: Neoprene faced Phenolic /Glass Reinforced Epoxy.
**B.** Insulation sleeve: Reinforced Phenolic/Nylon/Polyethylene.
**C.** Insulation washer: Reinforced Phenolic/Nylon/Polyethylene.
**D.** Plated Washer: Electro plated steel washer.
**Or** To **isolate between above ground and Underground.**

- **What is punch list?**

  List of unfinished work or unmatched item according to ISO, P & ID drawing and specs. before Hydro test.

- **What is the use of Lateral:**

  Limit fluids resistance and minimize chock of pipe due to foreign material (refer–ASME B 16.9)

- **What is a P & ID?**

  Piping / process and instrument diagram will show the piping/process layout and detailed notes relating to piping/process and instrumentation.

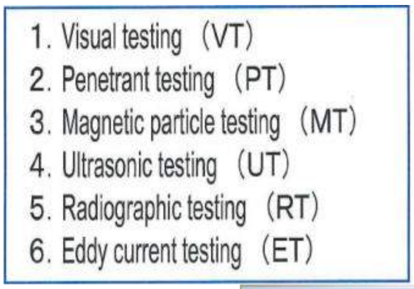
- **What is piping isometric drawing?**

  Detailed piping system/ line drawing with reference to construction and material requirements , Line conditions, materials of construction, elevations, Orientation, piping and drawing details and notes, revision control and approval Status..etc.

- **What is Line Routing Diagram?**

  A line routing diagram is a schematic representation of all process and utility-piping system drawn on a copy of plot plan. This diagram does not show the exact locations, elevations or interference but it locates the area / place.

- **Types of Non-Destructive Examination:**



1. Visual testing (VT)
2. Penetrant testing (PT)
3. Magnetic particle testing (MT)
4. Ultrasonic testing (UT)
5. Radiographic testing (RT)
6. Eddy current testing (ET)

Visual Examination

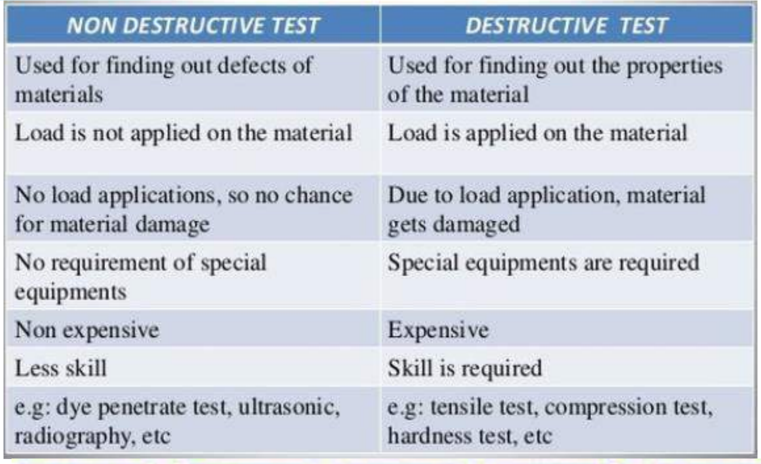
Liquid Penetrant Testing

Magnetic Particle Testing

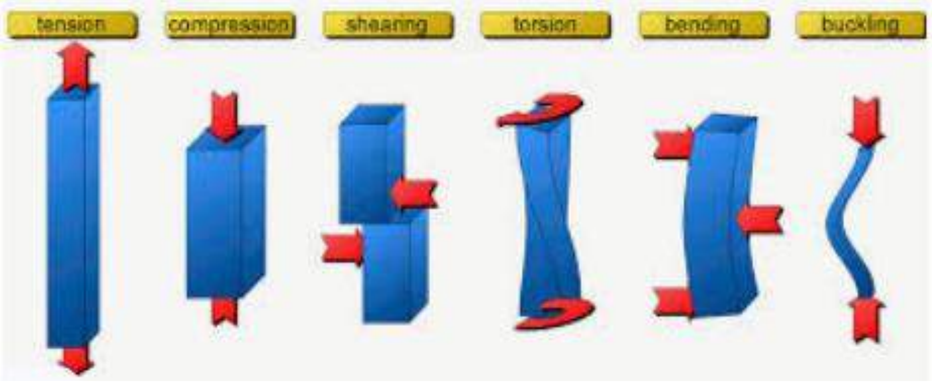
Eddy Current Testing

Radiography

Ultrasonic Testing

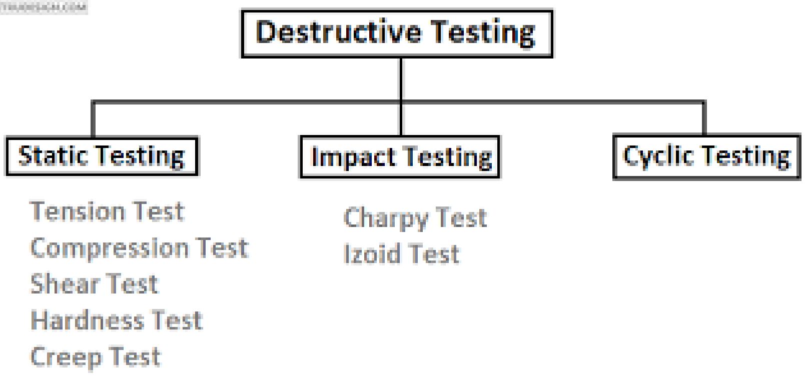


| NON DESTRUCTIVE TEST | DESTRUCTIVE TEST |
|---|---|
| Used for finding out defects of materials | Used for finding out the properties of the material |
| Load is not applied on the material | Load is applied on the material |
| No load applications, so no chance for material damage | Due to load application, material gets damaged |
| No requirement of special equipments | Special equipments are required |
| Non expensive | Expensive |
| Less skill | Skill is required |
| e.g: dye penetrate test, ultrasonic, radiography, etc | e.g: tensile test, compression test, hardness test, etc |

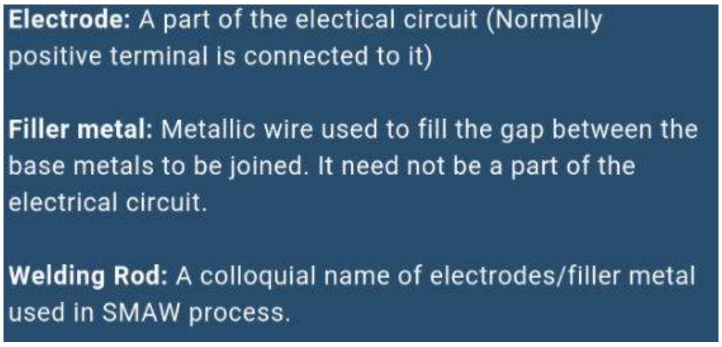

tension
compression
shearing
torsion
bending
buckling

- **Types of Destructive Examination :**

EXTRUDESIGN.COM


Destructive Testing
Static Testing
Impact Testing
Cyclic Testing
Tension Test
Compression Test
Shear Test
Hardness Test
Creep Test
Charpy Test
Izoid Test

- **What is difference between welding rod and electrode?**

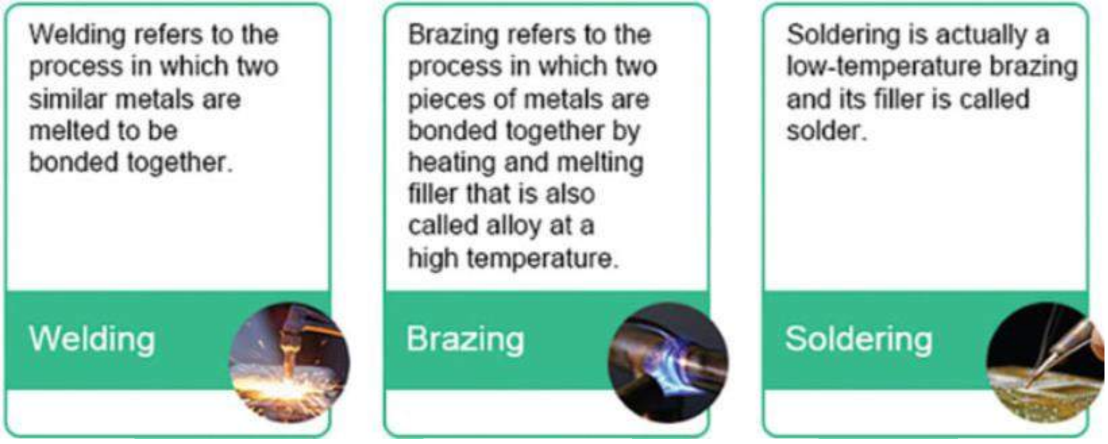


**Electrode:** A part of the electical circuit (Normally positive terminal is connected to it)

**Filler metal:** Metallic wire used to fill the gap between the base metals to be joined. It need not be a part of the electrical circuit.

**Welding Rod:** A colloquial name of electrodes/filler metal used in SMAW process.

- **What are differences between Welding, soldering & Brazing?**



Welding refers to the process in which two similar metals are melted to be bonded together.

Brazing refers to the process in which two pieces of metals are bonded together by heating and melting filler that is also called alloy at a high temperature.

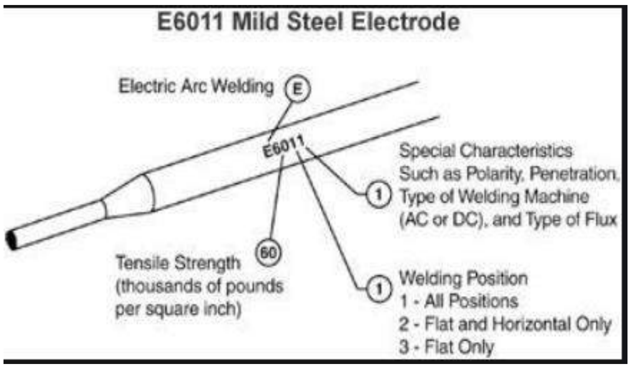
Soldering is actually a low-temperature brazing and its filler is called solder.

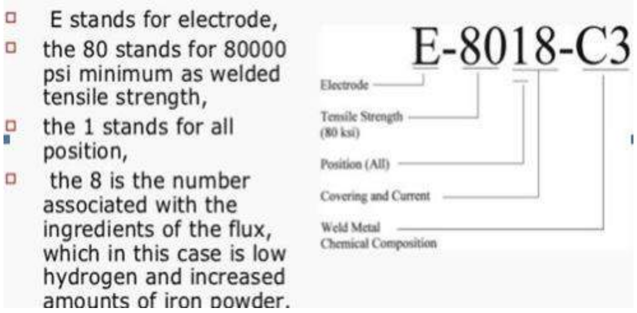
Welding
Brazing
Soldering

The main **difference between** the process of **welding** and **soldering** is melting since **soldering** involves heating of the metal to be bonded rather than melting. In **welding**, fabricators melt the base metal, causing fusion. **Brazing**, on the other hand, combines metals by melting and flowing filler metal right into its joint.

- **What Backing gas should be used when welding stainless steel or Alloy steel and what shall be the purity of this Gas?** Argon – 99.9 %.

- **Welding rod & what does number indicate?**

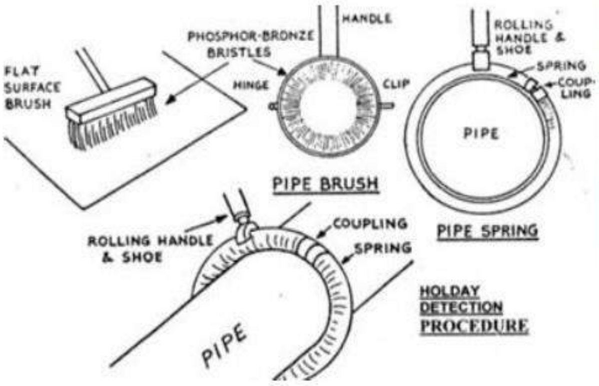

E6011 Mild Steel Electrode
Electric Arc Welding
E
E6011
Special Characteristics Such as Polarity, Penetration, Type of Welding Machine (AC or DC), and Type of Flux
1
Tensile Strength (thousands of pounds per square inch)
60
Welding Position
1
1 - All Positions
2 - Flat and Horizontal Only
3 - Flat Only



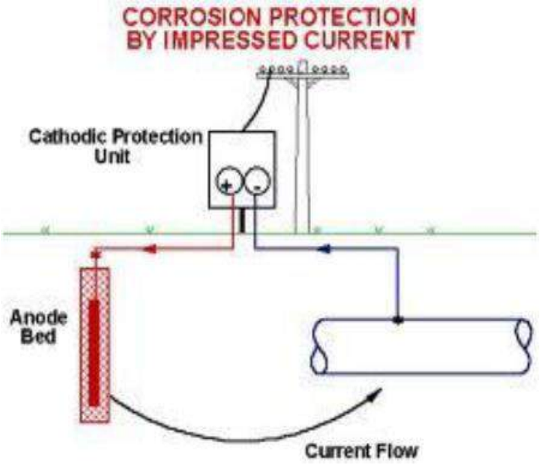
- E stands for electrode,
- the 80 stands for 80000 psi minimum as welded tensile strength,
- the 1 stands for all position,
- the 8 is the number associated with the ingredients of the flux, which in this case is low hydrogen and increased amounts of iron powder.

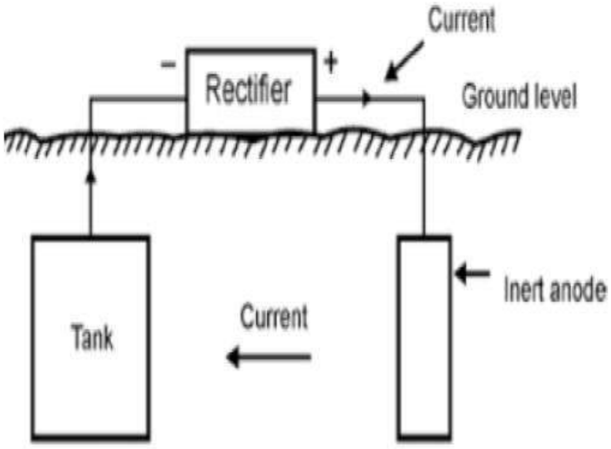
E-8018-C3
Electrode
Tensile Strength (80 ksi)
Position (All)
Covering and Current
Weld Metal Chemical Composition

- **What does holiday detector detect** :
  Pin holes in Coating and Wrapping.


FLAT SURFACE BRUSH
PHOSPHOR-BRONZE BRISTLES
HANDLE
HINGE
CLIP
PIPE BRUSH
ROLLING HANDLE & SHOE
SPRING
COUP-LING
PIPE
PIPE SPRING
ROLLING HANDLE & SHOE
COUPLING
SPRING
PIPE
HOLDAY DETECTION PROCEDURE

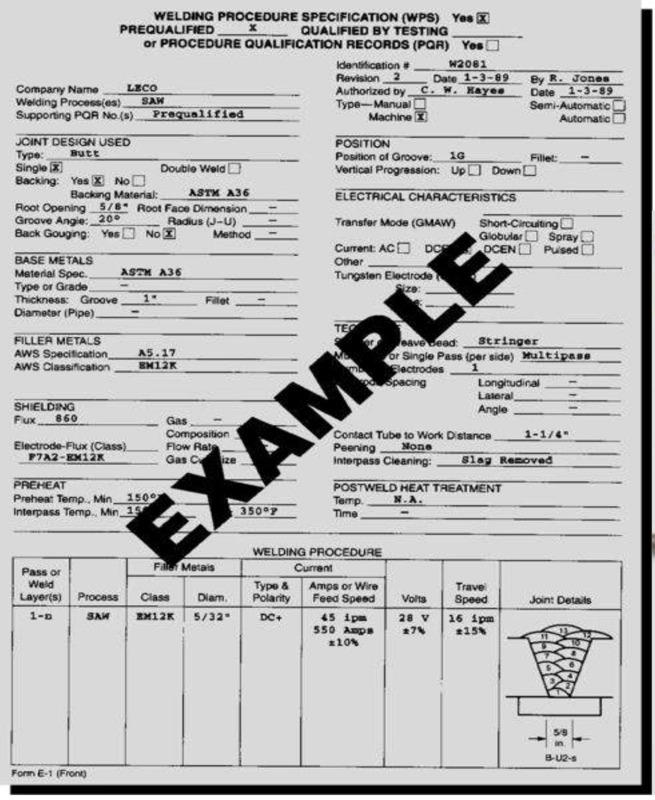
- **What is cathodic protection?**
  Way of protecting metal against corrosion by passing a small electric current between the metal surface and the surrounding ground or water.


CORROSION PROTECTION BY IMPRESSED CURRENT
Cathodic Protection Unit
Anode Bed
Current Flow


Current
Rectifier
-
+
Ground level
Tank
Current
Inert anode

Different types of Anodes are used in cathodic protection are Magnesium, Zinc, High Silicon Iron, Aluminum etc.

**WHAT IS WPS? Welding procedure specification** is a specification for all the piping materials and filler material which will be used.



**WELDING PROCEDURE SPECIFICATION (WPS)** Yes ☒
**PREQUALIFIED** X **QUALIFIED BY TESTING** 
**or PROCEDURE QUALIFICATION RECORDS (PQR)** Yes ☐

Identification # W2081
Revision 2 Date 1-3-89 By R. Jones
Authorized by C. W. Hayes Date 1-3-89
Type—Manual ☐ Semi-Automatic ☐
Machine ☒ Automatic ☐

Company Name LECO
Welding Process(es) SAW
Supporting PQR No.(s) Prequalified

JOINT DESIGN USED
Type: Butt
Single ☒ Double Weld ☐
Backing: Yes ☒ No ☐
Backing Material: ASTM A36
Root Opening 5/8" Root Face Dimension –
Groove Angle: 20° Radius (J–U) –
Back Gouging: Yes ☐ No ☒ Method –

POSITION
Position of Groove: 1G Fillet: –
Vertical Progression: Up ☐ Down ☐

ELECTRICAL CHARACTERISTICS
Transfer Mode (GMAW) Short-Circuiting ☐
Globular ☐ Spray ☐
Current: AC ☐ DC[illegible] DCEN ☐ Pulsed ☐
Other
Tungsten Electrode [illegible]
Size:
[illegible]:

BASE METALS
Material Spec. ASTM A36
Type or Grade –
Thickness: Groove 1" Fillet –
Diameter (Pipe) –

FILLER METALS
AWS Specification A5.17
AWS Classification EM12K

TEC[illegible]
[illegible] eave Bead: Stringer
[illegible] or Single Pass (per side) Multipass
[illegible] Electrodes 1
[illegible] Spacing Longitudinal –
Lateral –
Angle –

SHIELDING
Flux 860 Gas –
Composition
Electrode-Flux (Class) Flow Rat[illegible]
F7A2-EM12K Gas C[illegible]ize

Contact Tube to Work Distance 1-1/4"
Peening None
Interpass Cleaning: Slag Removed

PREHEAT
Preheat Temp., Min 150°F
Interpass Temp., Min 15[illegible] 350°F

POSTWELD HEAT TREATMENT
Temp. N.A.
Time –

EXAMPLE

WELDING PROCEDURE

| Pass or Weld Layer(s) | Process | Filler Metals |  | Current |  | Volts | Travel Speed | Joint Details |
|---|---|---|---|---|---|---|---|---|
|  |  | Class | Diam. | Type & Polarity | Amps or Wire Feed Speed |  |  |  |
| 1-n | SAW | EM12K | 5/32" | DC+ | 45 ipm<br>550 Amps<br>±10% | 28 V<br>±7% | 16 ipm<br>±15% | 1 2 3 4 5 6 7 8 9 10 11 12 13<br>5/8 in.<br>B-U2-s |

Form E-1 (Front)

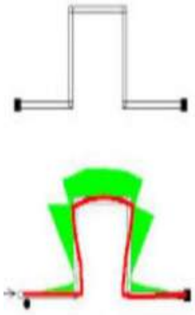
EXCALIBUR 7018 H4R
309/309L-16 LOT 752Y
6011
6013
308/308L-17 LOT 7U9Y BLUE MAX
6013
6010
6010
7010
7014
PREMIER EP+

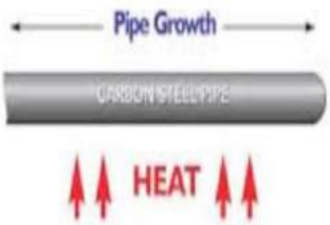
- **Which is the Electrode & filler wire used for welding of following materials?**

| **Base metal ( ASTM / ASME ) Product Forms** |  |  |  |  | **Welding Metal ( AWS )** |  |
|---|---|---|---|---|---|---|
| **PLATE** | **PIPE** | **FORGING** | **TUBE** | **CASTING** | **ELECTRODE (SMAW)** | **FILLER METAL (GTAW)** |
| **CARBON STEEL** |  |  |  |  |  |  |
| A516 GR. 70<br>A515 GR. 70<br>A285 GR. B | A106 GR.B<br>API 5L GR.B<br>A53 GR.B | A105 | A179 | A216- WCB | E - 7018 | ER –70S-2 |
| **LOW ALLOY STEEL** |  |  |  |  |  |  |
| A387 GR.1 | A335 – P1 | A182-F1 | A213-T1 | A217-WC1 | E-7018-A1 | ER-80S-G |
| A387 GR.12 | A335 – P12 | A182-F12 | A213-T12 | A217-WC4 | E-8018-B2 | ER-80S-B2 |
| A387 GR.22 | A335 – P22 | A182-F22 | A213-T22 | A217-WC9 | E-9018-B3 | ER-90S-B3 |
| **STAINLESS STEEL** |  |  |  |  |  |  |
| A240-304L | A312-TP304L | A182-F304L | A213-TP304L | A351-CF3 | E 308L-16 | ER-308L |
| A240-316L | A312-TP316L | A182-316L | A213-TP316L | A351-CF3M | E 316L-16 | ER-316L |

**What is an expansion loop?**

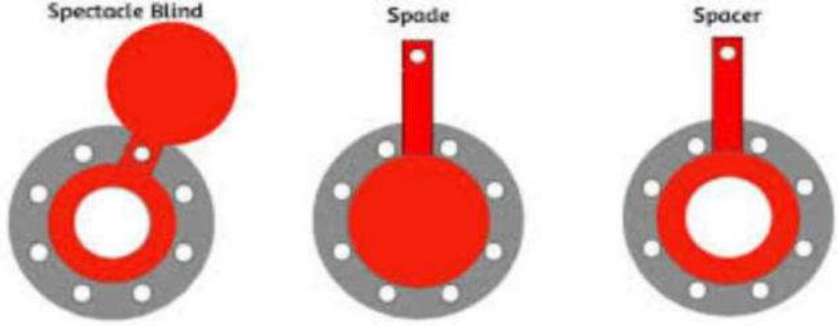
Expansion loop is the piping arrangement, which allows the movement of the pipe during operation with high temperature and pressure and during the shutdown; piping will come down to cool condition. During both periods, with the help of Expansion Loop, the pipes are Expand / contract accordingly.





- **Material Inspection :**
  a) How do you verify the material?
  Mill Certificate, heat number, color coding and PMI, schedule, rating, Carbon equivalent Value for PREHEAT, diameter, class, grade.
  b) How do you identify fitting and flanges?
  Correct ratings, sizes, class, schedules as marked on fittings & mill certificates.
  c) How do you check piping for the correct schedule?
  Use a Vernier Caliper and ensure piping is within tolerances.
  d) What are the tolerances for physical piping straightness and defects?
  Check the ASTM/ASME or API piping specification/Std.

- **What kind of the inspection required during Gasket installation?**
  Check the Gasket material as per the drawing and specification, size, rating and visual Inspection of surface damages.
- **Explain 'Spectacle' plate :**
  Used for Service and shutdown (isolation) for maintenance purposes.



- **What is Jack Screws and when are they required?**
  They are located at flanged connections to facilitate maintenance and removal of flange and Orifice plates to facilitate maintenance.
- **Check list for reinstatement** :
  # Check that correct bolts and gaskets are installed at all reinstated joints.
  # Check that all process blinds and spades have been correctly installed as ISO ,P&ID.
  # Check that spectacle blinds are in the correct position.
  # Check that correct valves have been installed in the correct 'Flow' position.
  # Check that all valves are functioning properly and that spindle has been coated /greased (if required).
  # Check that PSV / TSV, relief valve have been correctly installed.
  # Check that all pump suction strainers have been correctly installed.
  # check that correct flow through filters/strainers, traps, check valves and globe valves etc..
  # Release for final equipment alignment & check piping stress , support..etc.
  # Hydro test completed.
- **HYDRO TEST PACKAGE REVIEW** : (refer API -570)
  1) P&ID for correct revision.
  2) Isometric drawing for correct revision & confirm to P&ID.
  3) Boundaries of hydro test, filling / draining / vent point and ensure all necessary P&ID's /Isometric are in the package.
  4) Ensure all line listed in test package are identified and test pressure is correct.
  5) Check blind lists of sizes, thickness and rating.
  6) Check exception list.
  7) The test medium and pressure.
  8) Pressure gauges calibration / size
  9) Hydro test water quality / ppm
- **THE CHECK LIST FOR PIPING WORK COMPLETION NEEDS TO BE CONFIRMED BEFORE THE PRESSURE TEST START:**

1) Piping should be Correct Dimension, Location and Orientation.
2) Welding Completed.
3) NDE Completed.
4) PWHT and Hardness Test Completed.
5) Valve, in line item and line Equipment Completed.
6) Support and Hanger installation Completed.
7) Material Thickness Verification / Color Code
8) P&ID Walk through in accordance with Isometric drawings.
9) All instruments are disconnected or not.

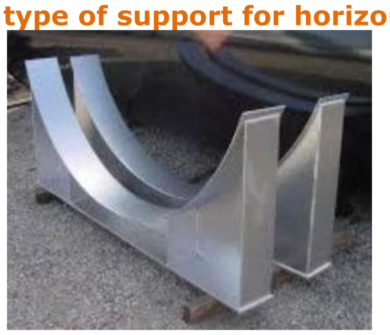
- **BEFORE THE HYDRO TESTING COMMENCES SOME OF THE GENERAL REQUIREMENT TO BE CHECK AND REVIEW.**
  1) Test Pressure to be used shall not less than 1.5 times the design pressure.
  2) Water to be used shall be fresh water and free from sediments. The Maximum Chloride content shall be less than 30 ppm.
  3) For Pneumatic testing, the test medium shall be Air or any other non-flammable gas and the test pressure shall be 110 % of the design pressure. For pneumatic test, the soap solution spray shall be used during leakage detection.
  4) The Temporary supports are to be examined to ensure that they will adequately support the line during testing.
- **HYDRO /AIR TEST SEQUENCES ARE** :

1) Filling Test System Completely with water or Air.
2) Fill the water from the down side.
3) Open all vent valves during Water filling.
4) Applying pressure gradually until the specified test pressure is reached.
5) Holding time is 10 minutes minimum. The test pressure is attained until all welds and connection have been examined. ( shall not over pressurize the system )
6) After the test, the system was drained to minimize standing water in the line. Air blowing to be performed to remove the remaining water.

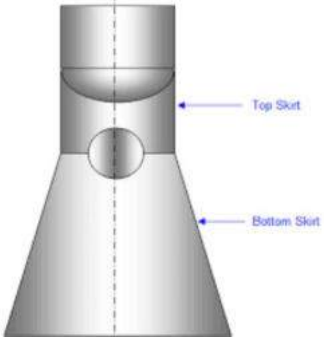
- **SOME APPLICABLE CHECK POINT FOR PUNCH :**
  1) Completion of Welding Inspection Report
  2) Appearance of welding joints - strike, fillet size etc
  3) Distance Between weld closeness
  4) Orifice flange, Nozzle orientation.
  5) Position of welding earth structure and temporary support.
  6) Deformation of material.
  7) Weep hole, support, and PSV vent
  8) Branch and Nozzle Orientation, location.
  9) Verticality, Horizontality and slope of line as per isometric drawing.
  10) Piping connection to Equipment nozzle. Extra force or movement is prohibited.
  11) Support and shoe location, removal, clearance.
  12) Gasket material, size, gasket std.
  13) Valve. -Material, size, flow direction.
  14) Bolt & nuts.-Material, size, length, tightness
  15) Jack screw.-Material, size.
  16) Drain and vent.-Size, orientation.
  17) Piping line class break. Location, rating class as shown in P&ID / ISO.
- **FINAL PUNCH LIST POINT :**

1) To install permanent gasket after test.
2) Apply Molykoat to all bolts.
3) Bolt Length should be correct.
4) Apply Grease to all Valve spindles.
5) Re install cap with Teflon tape.

- **What type of support for horizontal vessel?** Saddle support.



- **What type of support for Vertical vessel?** Skirt support.

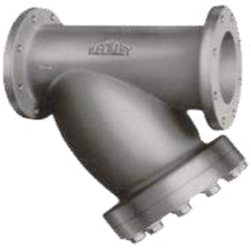


- **What is the minimum class rating for a Control Valve/bypass valve / orifice flange?** 300# lbs.
- **What is a Flare?** A system that disposes the plants waste gases at elevated height.
- **What is HAZOP? HAZOP** is an **abbreviation of Hazard and Operability**. It is the most widely used method for the identification of hazards , studies are carried out for risk assessment for facility
- **What are the common basic functions of Instruments?**
  1) Sense 2) transmit 3) indicate 4) record and 5) control.

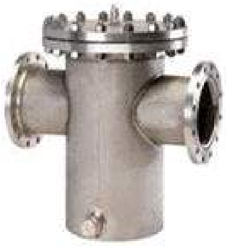
**Strainers:**

A pipe line strainer is a device which provides a means of mechanically removing solids form a flowing fluid by utilizing a perforated, mesh or wedge wire straining element, Strainer for coarse size, Filter is more accurate than Strainer.

**Types of Strainers -** Two frequently specified strainers are the "Y" strainer and the basket strainer and others are Duplex/Twin Strainers, Tee strainers, Geometric (Temporary), Automatic Self-Cleaning Strainers.



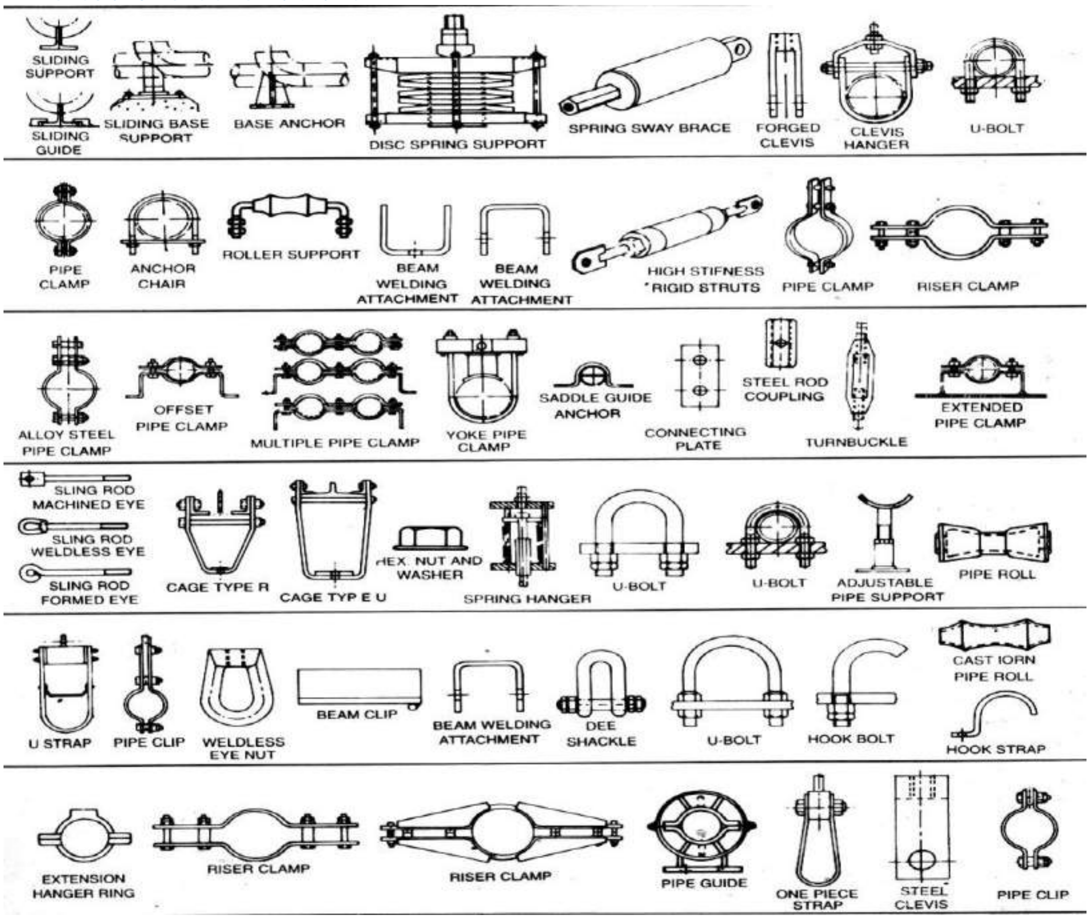
Y-strainer



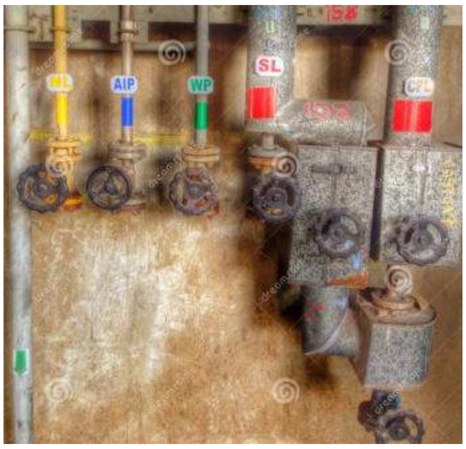
bucket strainer

- **What are the differences between Y-strainer and bucket strainer? Which is better for petroleum service?**
  As its name implies, **Y-strainer** has the shape of letter Y. Its tail end allows easy access to remove the solids and to clean the strainer. The strainer can be mounted horizontally, or vertically.
  **Bucket type strainer** has vertical cylinder, or chamber, larger than in Y-strainer. The straining area is larger allowing for longer time between cleaning. The flow is less hampered by debris so the pressure drop across is less than in Y-strainer. Bucket strainer is preferred in larger diameter pipes, in services where longer maintenance interval is desired, or where pressure drop has to be minimized for NPSH reason. Bucket type strainer, also known as basket strainer, is mounted horizontally.

- **Pipe Support types are defined as follows** :
  - a) Anchor – a support fixing the piping completely.
  - b) Guide – a support restricting the movement perpendicular to pipe axis, but the axial movement is allowed.
  - c) Hanger – a support hanging the piping.
  - d) Spring – a resilient support which allows vertical movement.
  - e) Resting support – a simple support bearing the pipe weight only.
  - f) Directional stop – a support restricting the movement of a certain direction.
  - g) 3 Way restraint- a support restricting the movements of three directions, but permitting the rotation.
  - h) Pick up support: a support resting small diameter pipe using large diameter pipe instead of steel structure.


SLIDING SUPPORT
SLIDING GUIDE
SLIDING BASE SUPPORT
BASE ANCHOR
DISC SPRING SUPPORT
SPRING SWAY BRACE
FORGED CLEVIS
CLEVIS HANGER
U-BOLT
PIPE CLAMP
ANCHOR CHAIR
ROLLER SUPPORT
BEAM WELDING ATTACHMENT
BEAM WELDING ATTACHMENT
HIGH STIFNESS RIGID STRUTS
PIPE CLAMP
RISER CLAMP
ALLOY STEEL PIPE CLAMP
OFFSET PIPE CLAMP
MULTIPLE PIPE CLAMP
YOKE PIPE CLAMP
SADDLE GUIDE ANCHOR
CONNECTING PLATE
STEEL ROD COUPLING
TURNBUCKLE
EXTENDED PIPE CLAMP
SLING ROD MACHINED EYE
SLING ROD WELDLESS EYE
SLING ROD FORMED EYE
CAGE TYPE R
CAGE TYP E U
HEX NUT AND WASHER
SPRING HANGER
U-BOLT
U-BOLT
ADJUSTABLE PIPE SUPPORT
PIPE ROLL
U STRAP
PIPE CLIP
WELDLESS EYE NUT
BEAM CLIP
BEAM WELDING ATTACHMENT
DEE SHACKLE
U-BOLT
HOOK BOLT
CAST IORN PIPE ROLL
HOOK STRAP
EXTENSION HANGER RING
RISER CLAMP
RISER CLAMP
PIPE GUIDE
ONE PIECE STRAP
STEEL CLEVIS
PIPE CLIP

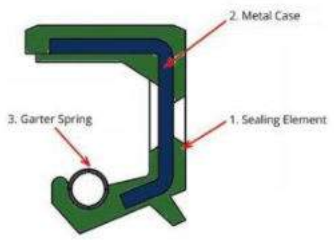
**Utility station:** Usually comprises four service lines carrying Steam, Utility/plant Air, Service Water and Nitrogen.( normal color coding for N2 –yellow , Water –green , Air –blue & steam –red ) .Hoses used for utility system need to be inspected and tested every year , normally to be replaced every 3-4 yrs .

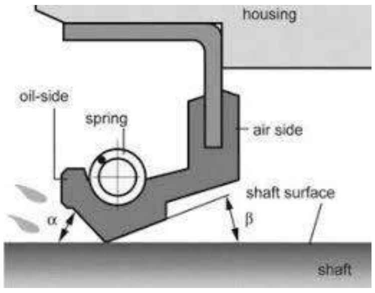


**FLANGE JOINT USING DIFFERENT RATINGS** :
Where flanges of different rating are bolted together, Bolting torque shall be limited so that excessive loads will not be imposed on the lower rated flange in obtaining a tight joint.

**NORMAL LOCATION FOR THE PRESSURE TEST GAUGE IN HYDRO /AIR TESTING:**
Basically required two nos. pressure gauges. One in the top side, and the other in the down side. Test pressure should be monitored only in the Top side pressure Gauge. Every 10 meter height, 1 barg head pressure to be added with the top side pressure readings. To control the accuracy of the readings, the pressure gauge range should be 1.5 times to 3.0 times of the test pressure. It is mandatory to use only the calibrated gauges.

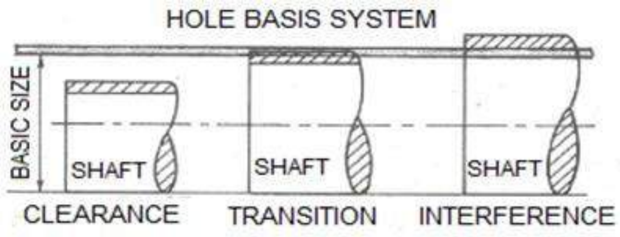
**Oil seal part** – spring, stiffener ring, inner shell & outer shell


2. Metal Case
3. Garter Spring
1. Sealing Element

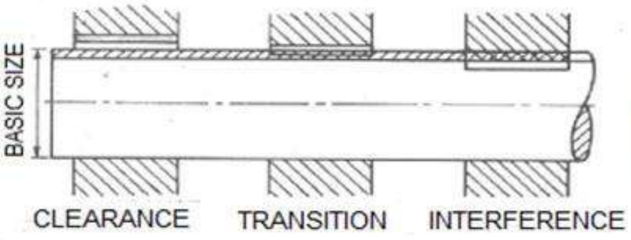

housing
oil-side
spring
air side
shaft surface
α
β
shaft

**What is different between mechanical seal and oil seal? Mechanical seal** use for arrest the leakages of any high pressure flow & Its One Part of rotating & another part is stationery and In case of **Oil Seal** is used for only oil leakages & its Stationery

**Fits and tolerance** –for interchangeability of parts, tolerances are 1) hole type 2) shaft type

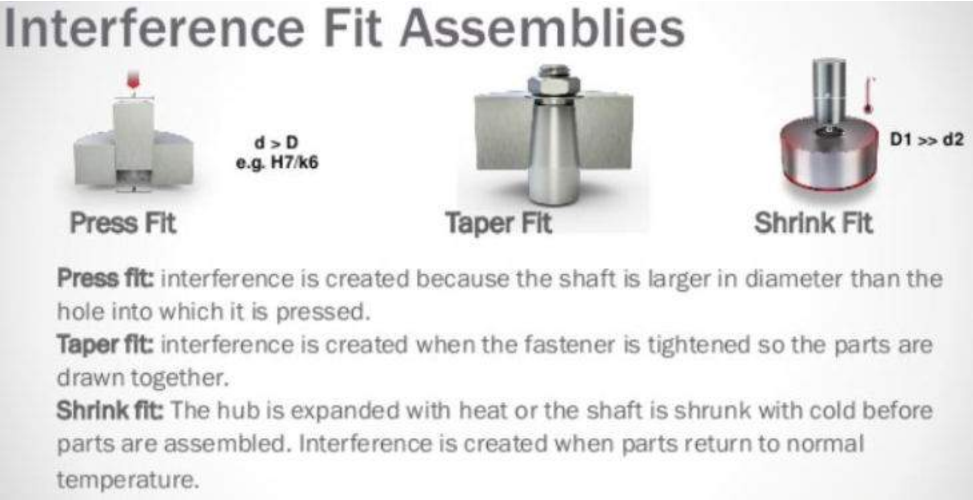

HOLE BASIS SYSTEM
BASIC SIZE
SHAFT
SHAFT
SHAFT
CLEARANCE
TRANSITION
INTERFERENCE

**HOLE BASED SYSTEM**
**Size of the Hole is kept constant, Shaft size is varied to get different fits**


BASIC SIZE
CLEARANCE
TRANSITION
INTERFERENCE

**SHAFT BASED SYSTEM**
**Size of the Shaft is kept constant, Hole size is varied to get different fits**

- **What is mean by Shrink fit & Press fit? Shrink fit** is a machined under fit that requires you to heat a component up to install and you let it cool down to fit tight on a shaft.
  **Press fit** is a machined fit that is normally 0.001 to 0.002" under size and you have to press it on.



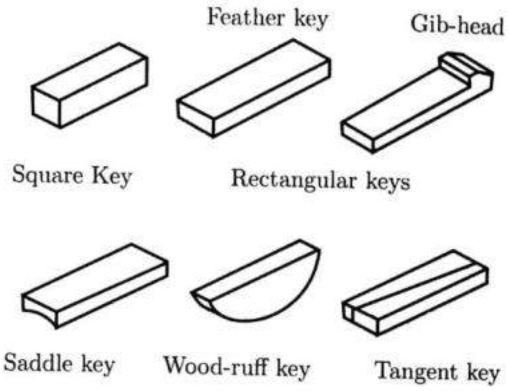
Interference Fit Assemblies

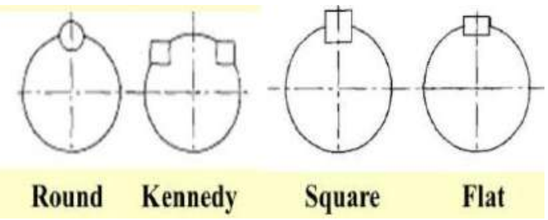
d > D
e.g. H7/k6
D1 >> d2
Press Fit
Taper Fit
Shrink Fit

**Press fit:** interference is created because the shaft is larger in diameter than the hole into which it is pressed.
**Taper fit:** interference is created when the fastener is tightened so the parts are drawn together.
**Shrink fit:** The hub is expanded with heat or the shaft is shrunk with cold before parts are assembled. Interference is created when parts return to normal temperature.

- **Types of keys –**
  1) Shunk key 2) Pin key 3) Feather key 4) Saddle key 5) Woodruff key 6) Splined key

**Normally length of key** is 1.5 d (d-shaft dia.) and made from steel bars having min. strength 58 kg/mm2( like – EN 8 steel , bearing steel ), **Can be repaired** of key and shaft / housing by-weld deposition , stepped key , new key way , knurling .


Feather key
Gib-head
Square Key
Rectangular keys
Saddle key
Wood-ruff key
Tangent key

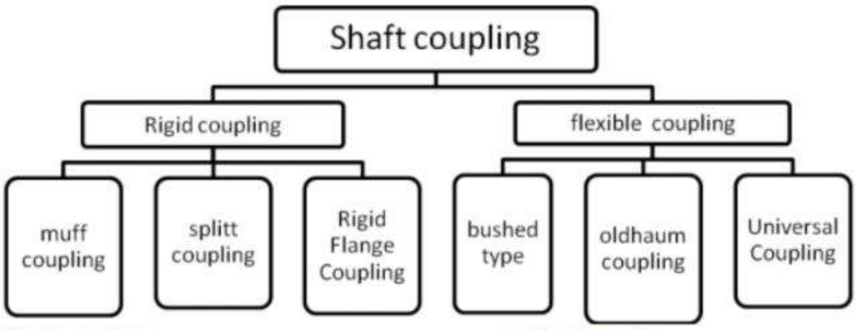

Round
Kennedy
Square
Flat

**washer** – thin circular plate made with central hole slightly bigger than bolt hole , thickness of washer 0.15d , washer are made from cold roller strip , brass strip , mild steel .

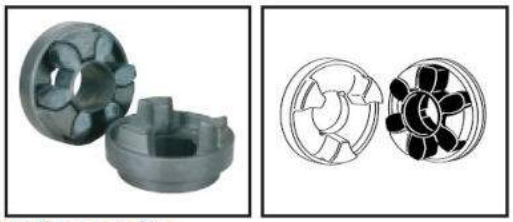
- **How to find spanner size:** 1.5 d , where d – nut and bolt size / dia .

- **Fly wheel** –
  1) Used in storing and given up energy whenever require during cycle.
  2) To regulate the speed from cycle to cycle.

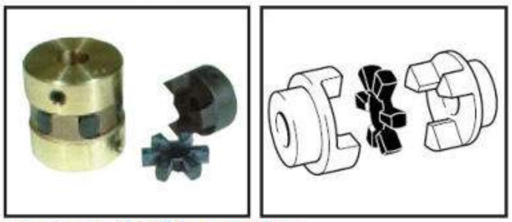
**Coupling:** coupling which joint two shafts together to transmit power.


Shaft coupling
Rigid coupling
flexible coupling
muff coupling
splitt coupling
Rigid Flange Coupling
bushed type
oldhaum coupling
Universal Coupling

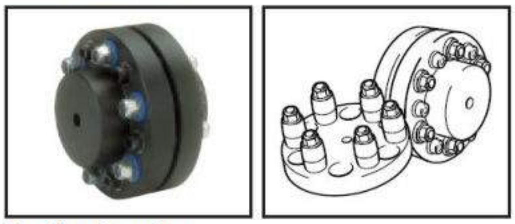
**Spiderflex Coupling**



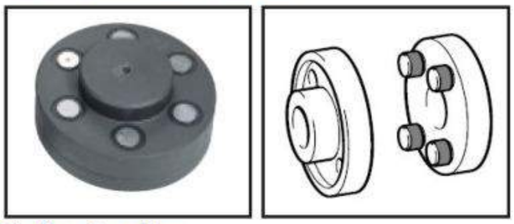
**Spider Coupling**



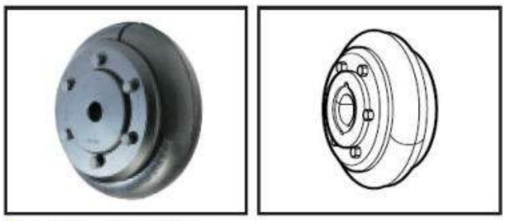
**Pinflex Coupling**



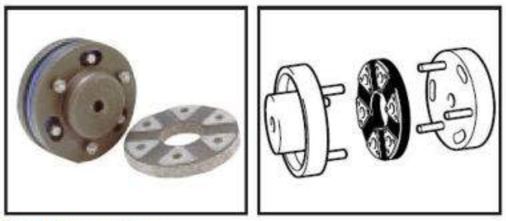
**Crownpin Flexible Coupling**



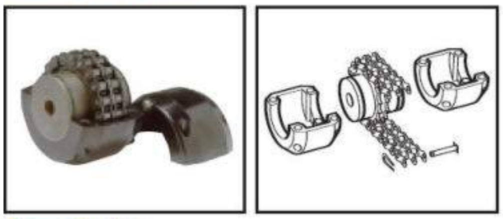
**Tyreflex Coupling**



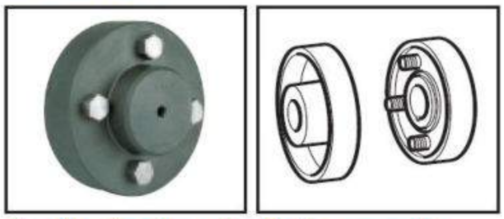
**Discflex Coupling**



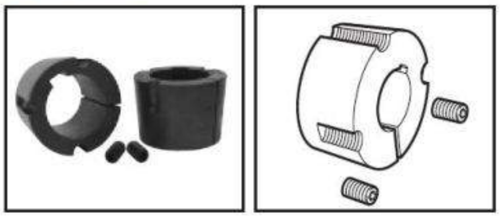
**Chainflex Coupling**



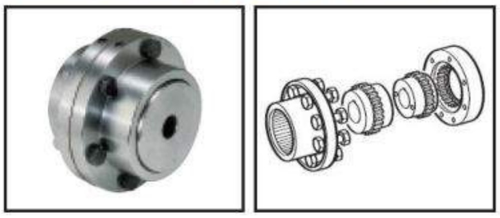
**Rigid Coupling**



**Taper Bushes**



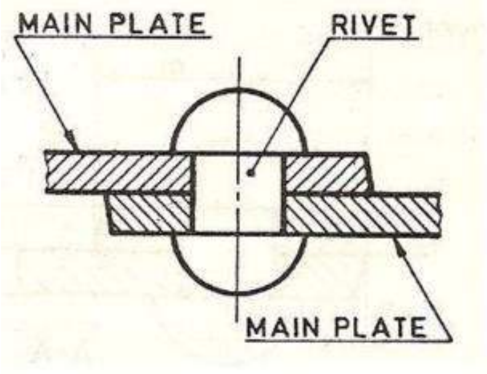
**Gearflex Coupling - Double Engagement**



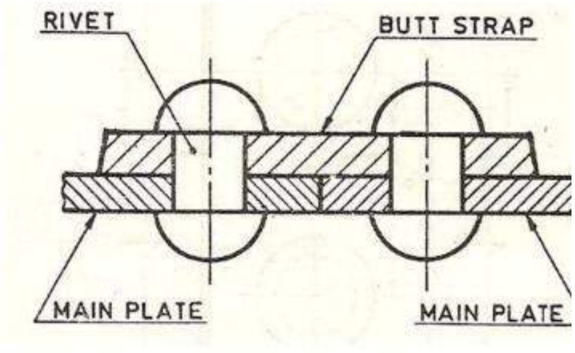
flexible
disc coupling

Universal coupling

**Rivet:** simplest kind of fastening and connecting parts in which strength is necessary.
**Types** – lap joint, butt joint.


MAIN PLATE
RIVET
MAIN PLATE

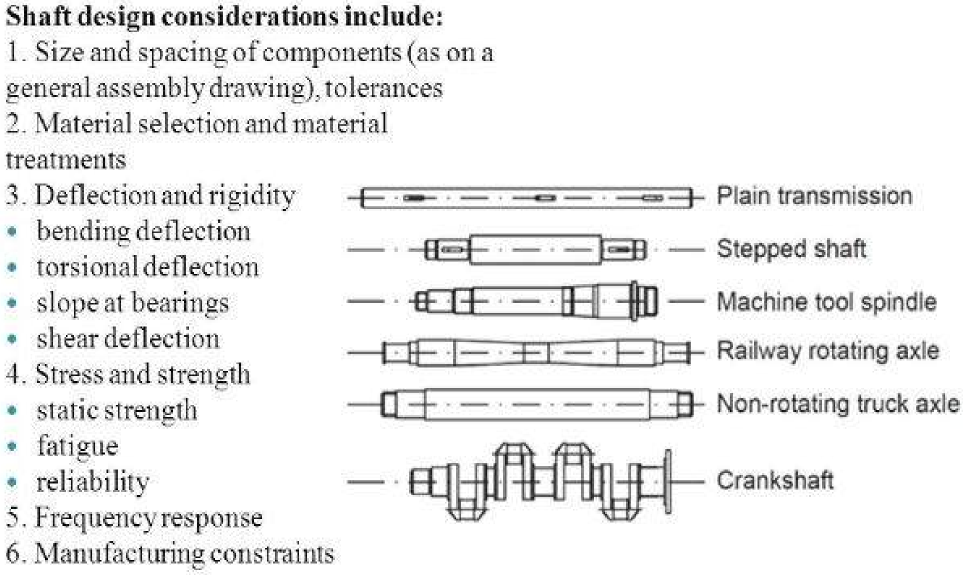
Lap joint


RIVET
BUTT STRAP
MAIN PLATE
MAIN PLATE

Butt joint

- **How to repair / remove broken bolts , studs / parts**
  1) By drilling hole less than object, 2) by using extractor tap having left hand thread.

- **Shaft:** shaft is rotating device which transmit power from one point to other,
  **Type**-hollow & solid, **Material**: made up of SS ,alloy steel, bearing material, CS ,MS.

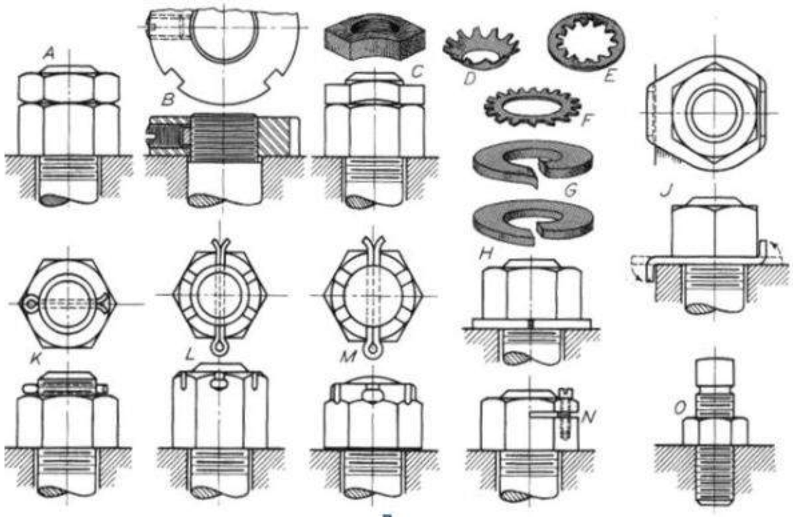


**Shaft design considerations include:**

1. Size and spacing of components (as on a general assembly drawing), tolerances
2. Material selection and material treatments
3. Deflection and rigidity
   - bending deflection
   - torsional deflection
   - slope at bearings
   - shear deflection
4. Stress and strength
   - static strength
   - fatigue
   - reliability
5. Frequency response
6. Manufacturing constraints

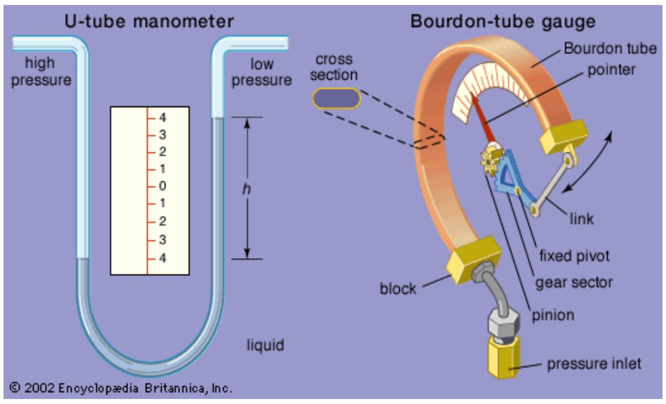
Plain transmission
Stepped shaft
Machine tool spindle
Railway rotating axle
Non-rotating truck axle
Crankshaft

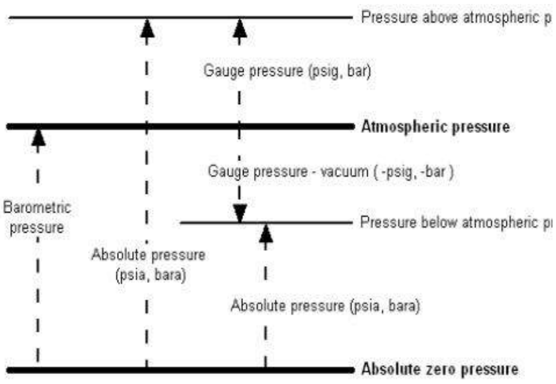
- **Types of locking devices –**
  1) Split pin 2 ) Lock nut 3) Lock washer 4 ) Spring washer…etc


A
B
C
D
E
F
G
H
J
K
L
M
N
O

- **Types of pressure gauges**
  Bourdon tube, Diaphragme, Capsule, Piston, Manomètre, Float type

✓ **To measure Atmospheric pressure** - barometer
✓ **To measure pressure between pipe** – manometer
✓ **Difference in pressure between two points** – differential pressure
✓ **Suction pressure is measured** by U tube manometer
✓ **Pilot tube is used** to measure velocity flow.


U-tube manometer
high pressure
low pressure
4
3
2
1
0
1
2
3
4
h
liquid
Bourdon-tube gauge
cross section
Bourdon tube
pointer
link
fixed pivot
gear sector
block
pinion
pressure inlet
© 2002 Encyclopædia Britannica, Inc.


Pressure above atmospheric p
Gauge pressure (psig, bar)
Atmospheric pressure
Gauge pressure - vacuum ( -psig, -bar )
Barometric pressure
Pressure below atmospheric p
Absolute pressure (psia, bara)
Absolute pressure (psia, bara)
Absolute zero pressure

**Insulation** - Advantages of insulation are…..Energy saving , Temp. control, Life protection , Conservation of product , Increase in productivity & Personnel protection and better working condition

**Types of insulation / lagging material**

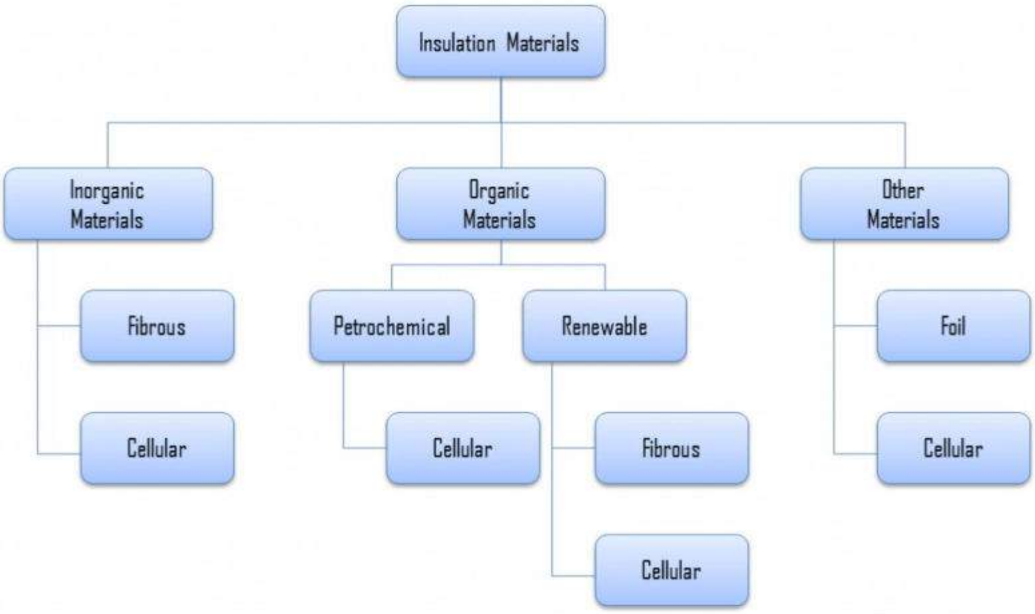
**Thermal insulation** is based on the use of substances with **very low thermal conductivity**. These materials are known as **insulation materials**. Common insulation materials are wool, fiberglass, rock wool, polystyrene, polyurethane, and goose feather etc. These materials are very poor conductors of heat and are therefore good thermal insulators.

A heat loss from hotter objects occurs by three mechanisms (either individually or in combination):

- Heat Conduction
- Heat Convection
- Thermal Radiation

**Types of Insulation – Categorization of Insulation Materials**

For insulation materials, three general categories can be defined. These categories are based on the chemical composition of the base material from which the insulating material is produced.


Insulation Materials
Inorganic Materials
Organic Materials
Other Materials
Fibrous
Cellular
Petrochemical
Renewable
Cellular
Fibrous
Cellular
Foil
Cellular

**Inorganic materials can be classified accordingly:**

- Fibrous materials
  - Glass wool
  - Rock wool
- Cellular materials
  - Calcium silicate
  - Cellular glass

**Organic Insulation Materials**

The organic insulation materials treated in this section are all derived from a petrochemical or renewable feedstock (bio-based). Almost all of the petrochemical insulation materials are in the form of polymers. All petrochemical insulation materials are cellular. A material is cellular when the structure of the material consists of pores or cells. On the other hand, many plants contain fibers for their strength; therefore almost all the bio-based insulation materials are fibrous (except expanded cork, which is cellular).

**Organic insulation materials can be classified accordingly:**

- Petrochemical materials (oil/coal derived)
  - Expanded polystyrene (EPS)
  - Extruded polystyrene (XPS)
  - Polyurethane (PUR)
  - Phenolic foam
  - Polyisocyanurate foam (PIR)

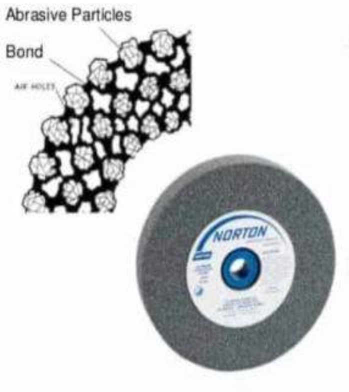
- Renewable materials (plant/animal derived)
    - Cellulose
    - Cork
    - Woodfibre
    - Hemp fibre
    - Flax wool
    - Sheeps wool
    - Cotton insulation

**Other Insulation Materials**

- Cellular Glass
- Aerogel
- Vacuum Panels

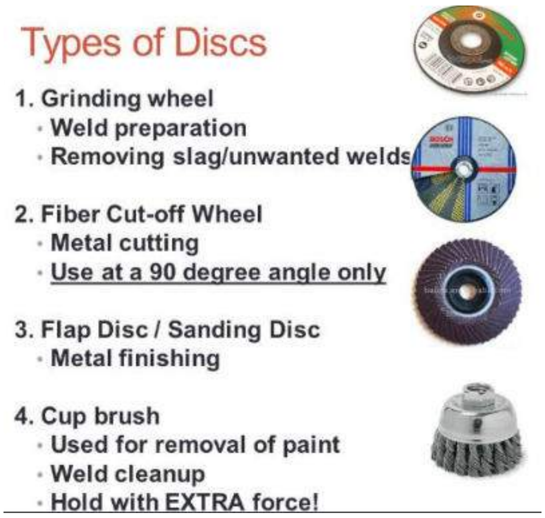
**Grinding – abrasive material are…**

- **Abrasives:** These are the mineral materials employed for sharpening, grinding & polishing operations.
- Abrasives are classified as natural & artificial.
- **Natural Abrasives:** Emery, Corundum, Diamond etc,.
- Artificial Abrasives: Silicon Carbide(SiC), Aluminum Oxide($Al_2O_3$), Cubic Boron Nitride(CBN) etc,.


Abrasive Particles
Bond
AIR HOLES
NORTON

- Grinding wheel consists of hard abrasive grains called grits, which perform the cutting or material removal, held in the weak bonding matrix.
- A grinding wheel commonly identified by the type of the abrasive material used.

**Selection of grinding wheel –** Material to be grind, Area of contact, Amount of area to be removed & Type of grinding m/c



Types of Discs

1. Grinding wheel
    - Weld preparation
    - Removing slag/unwanted welds
2. Fiber Cut-off Wheel
    - Metal cutting
    - Use at a 90 degree angle only
3. Flap Disc / Sanding Disc
    - Metal finishing
4. Cup brush
    - Used for removal of paint
    - Weld cleanup
    - Hold with EXTRA force!

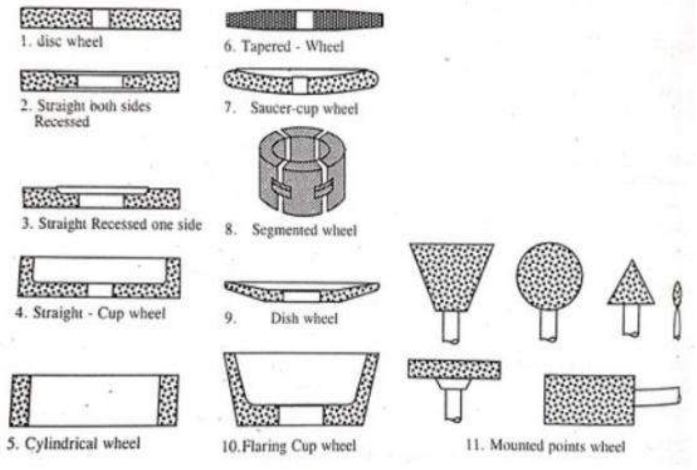
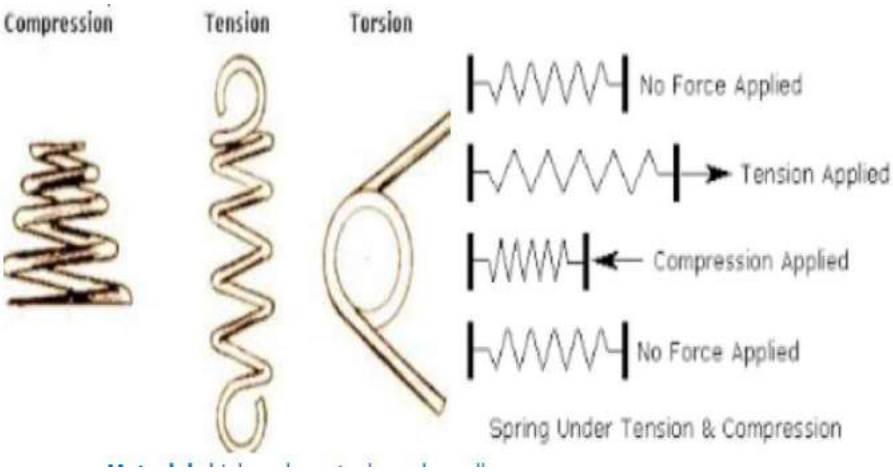

1. disc wheel
2. Straight both sides Recessed
3. Straight Recessed one side
4. Straight - Cup wheel
5. Cylindrical wheel
6. Tapered - Wheel
7. Saucer-cup wheel
8. Segmented wheel
9. Dish wheel
10. Flaring Cup wheel
11. Mounted points wheel

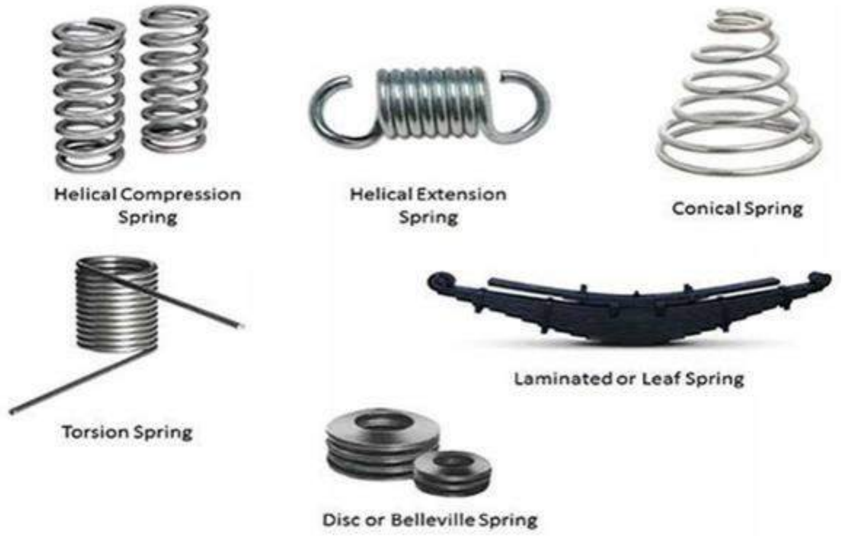
Diagram of all types of grinding wheel

- **Spring** – an elastic material which deflect or distort under load and recover its original position after load release.
  **Material**- high carbon steel, carbon alloy.
  **Type**- helical, compression, spiral, leaf, torsion, flat.


Compression
Tension
Torsion
No Force Applied
Tension Applied
Compression Applied
No Force Applied

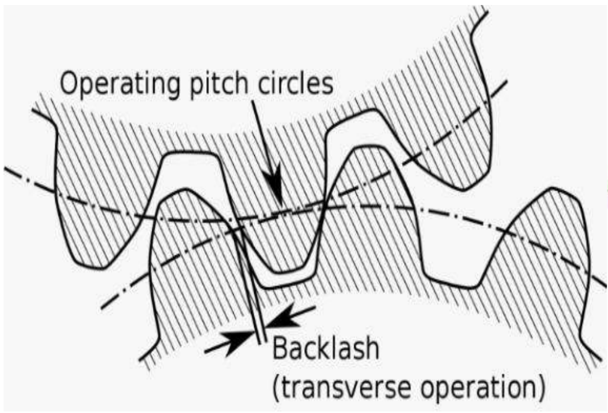
Spring Under Tension & Compression

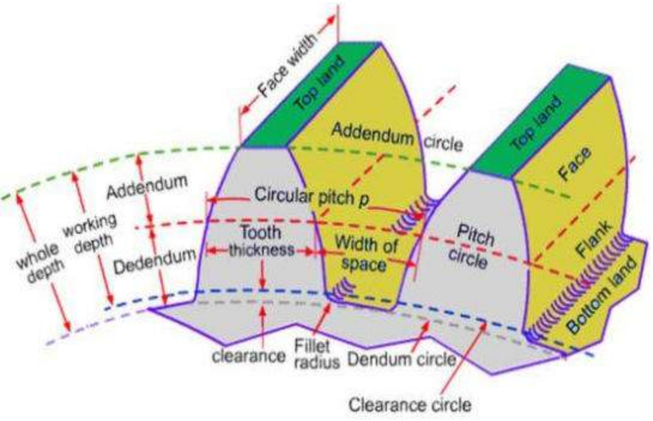
- **What are the different types of springs and explain them briefly?**


Helical Compression Spring
Helical Extension Spring
Conical Spring
Torsion Spring
Laminated or Leaf Spring
Disc or Belleville Spring

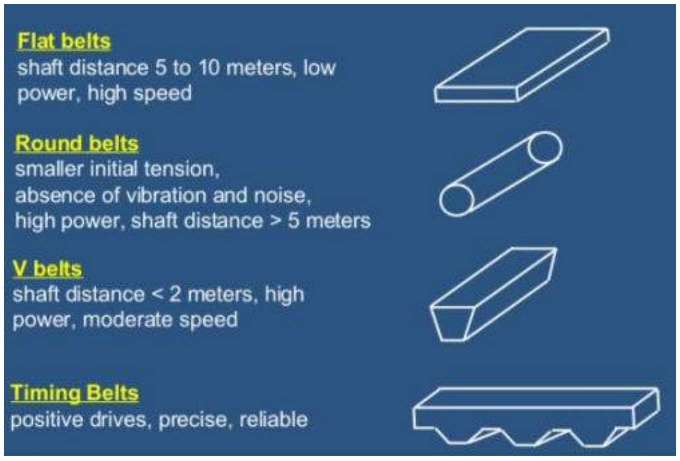
**Springs can be broadly classified into the following types:**
**Helical Springs:** These springs as their name suggests are in coil form and are in the shape of helix. The primary purposes of such springs are to handle compressive and tensile loads. They can be further classified into two types: compression helical spring and tension helical spring each having their own unique areas of application.
**Conical and volute springs**: Both these spring types have specialized areas of usage where springs with adaptable rate according to the load is required. In case of conical springs they are wound so as to have a uniform pitch while on the other hand volute springs are wound in a slight manner of a parabloid.
**Torsion Springs**: The characteristic of such springs is that they tend to wind up by the load. They can be either helical or spiral in shape. These types of springs are used in circuit breaker mechanisms.
**Leaf springs**: These types of springs are comprised of metal plates of different lengths held together with the help of bolts and clamps. Commonly seen being used as suspensions for vehicles.
**Disc Springs:** As the name suggests such types of springs are comprised of conical discs held together by a bolt or tube.

**Backlash**- the shortest distance between non driving surfaces of adjacent teeth in mating gears


Operating pitch circles
Backlash
(transverse operation)


Face width
Top land
Addendum circle
Top land
Face
Addendum
Circular pitch p
whole depth
working depth
Tooth thickness
Width of space
Pitch circle
Dedendum
Flank
Bottom land
clearance
Fillet radius
Dendum circle
Clearance circle

- **Belt** – **type**- flat, rope, V section , timing belt



**Flat belts**
shaft distance 5 to 10 meters, low power, high speed

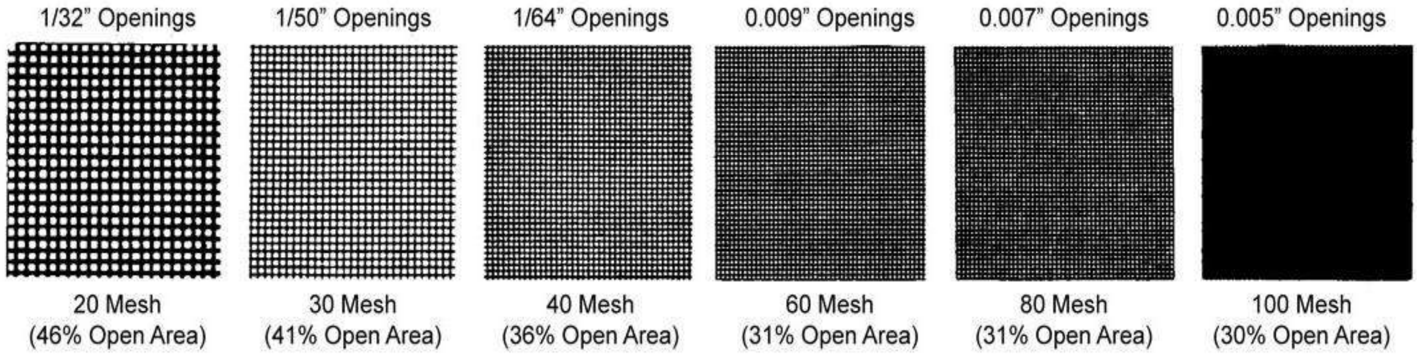
**Round belts**
smaller initial tension,
absence of vibration and noise,
high power, shaft distance > 5 meters

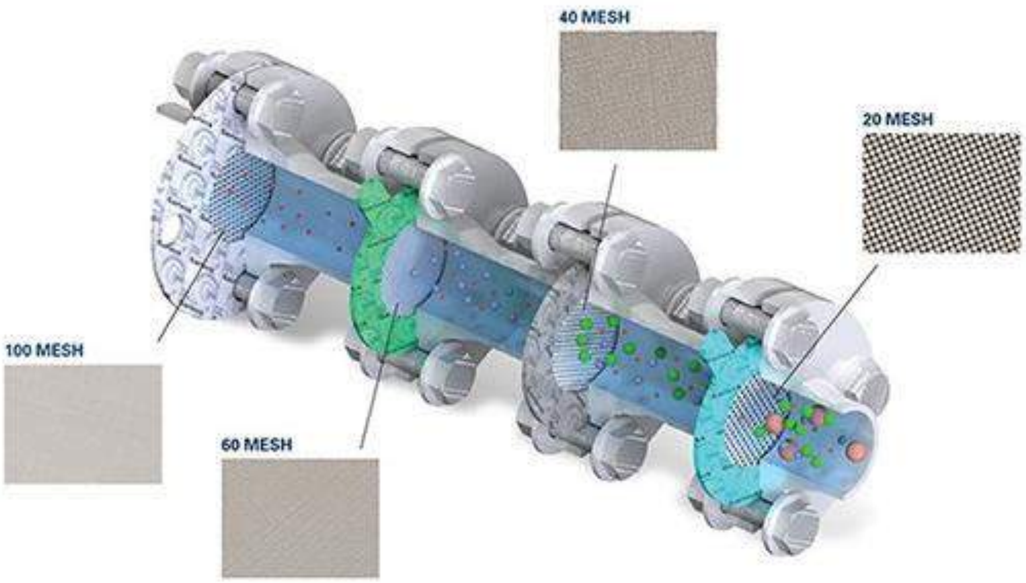
**V belts**
shaft distance < 2 meters, high power, moderate speed

**Timing Belts**
positive drives, precise, reliable

**Material** – leather, cotton, plastic cord, rubber, Balta.
V –belt transmit more power due to wedge action.
# **The number written on belt is in four digit** –last three digit indicate the length of belt in inches.
**Belt Creep** – loss of motion, loss of power to be transmitted due to partial slip.

- **what is mesh size in strainer**

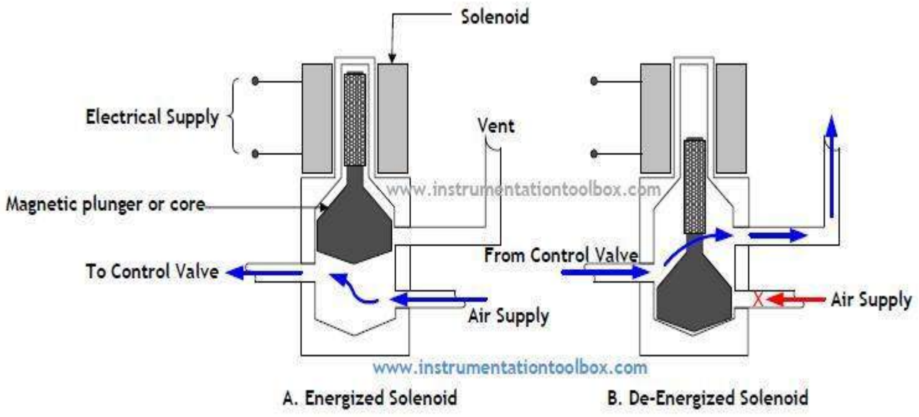

1/32" Openings
1/50" Openings
1/64" Openings
0.009" Openings
0.007" Openings
0.005" Openings
20 Mesh (46% Open Area)
30 Mesh (41% Open Area)
40 Mesh (36% Open Area)
60 Mesh (31% Open Area)
80 Mesh (31% Open Area)
100 Mesh (30% Open Area)


40 MESH
20 MESH
100 MESH
60 MESH

**Mesh size** for **strainers** is usually denominated in mm or microns however it can also be assigned a **mesh** number (which is number of holes per inch). **Mesh size** is fairly straightforward. It measures the number of openings in the **mesh** that make up one linear inch. For example, a 12 **mesh** screen means that there 12 openings across one inch There are some basic references of **size** of **mesh** but vary according to such things as heat, pressure and the nature of the material.

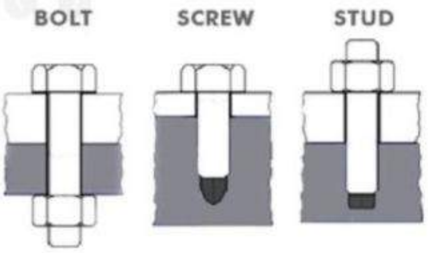
**What is a micron?** Micron is the measure of length most frequently used to describe tiny particle sizes. The term micron is actually a commonly used shorthand for micrometer (American spelling) or micrometre (international spelling). The official symbol for the micron or micrometer is µm, sometimes simplified as um. A micron is defined as one-millionth of a meter, a little more than one twenty-five thousandth of an inch.

- **Solenoid valve –** electrically operated two way shut off valve.

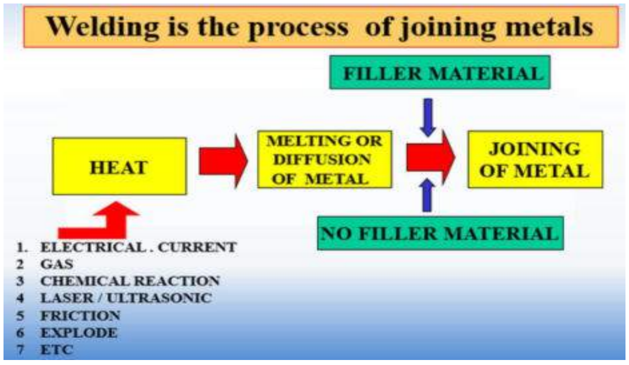

Solenoid
Electrical Supply
Vent
Magnetic plunger or core
www.instrumentationtoolbox.com
To Control Valve
From Control Valve
Air Supply
Air Supply
X
www.instrumentationtoolbox.com
A. Energized Solenoid
B. De-Energized Solenoid

**What is the difference between stud bolt and machine bolt?**

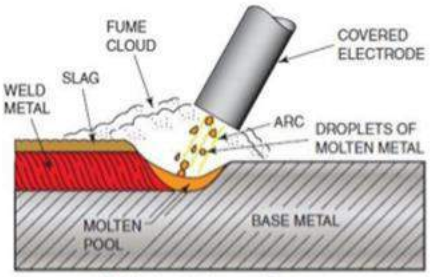
Machine bolt has a head on one side and nut on other side **but** stud bolts have nuts on both sides.


BOLT
SCREW
STUD

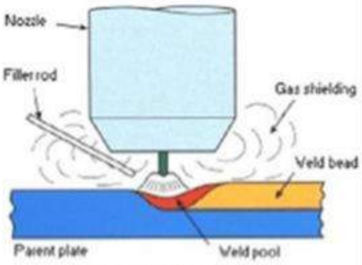
- **What is the Welding Process?**


Welding is the process of joining metals
FILLER MATERIAL
HEAT
MELTING OR DIFFUSION OF METAL
JOINING OF METAL
NO FILLER MATERIAL
1. ELECTRICAL . CURRENT
2 GAS
3 CHEMICAL REACTION
4 LASER / ULTRASONIC
5 FRICTION
6 EXPLODE
7 ETC

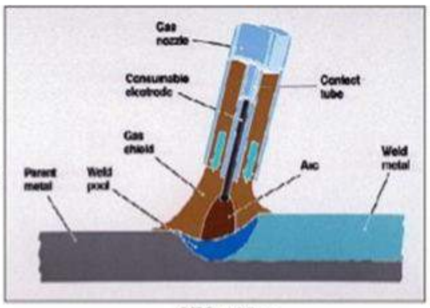
a) GTAW (Gas Tungsten Arc Welding)
b) SMAW (Shielded Metal Arc Welding)
c) SAW (Submerged Arc Welding)
d) FCAW (Flux Coated Arc Welding)
e) GMAW (Gas Metal Arc Welding)
f) PAW (Plasma Arc Welding)
g) TIG (Tungsten Inert Gas Welding).


FUME CLOUD
COVERED ELECTRODE
WELD METAL
SLAG
ARC
DROPLETS OF MOLTEN METAL
MOLTEN POOL
BASE METAL

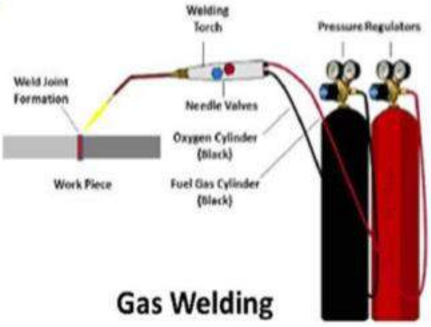
Shielded metal arc welding.


Nozzle
Filler rod
Gas shielding
Weld bead
Parent plate
Weld pool

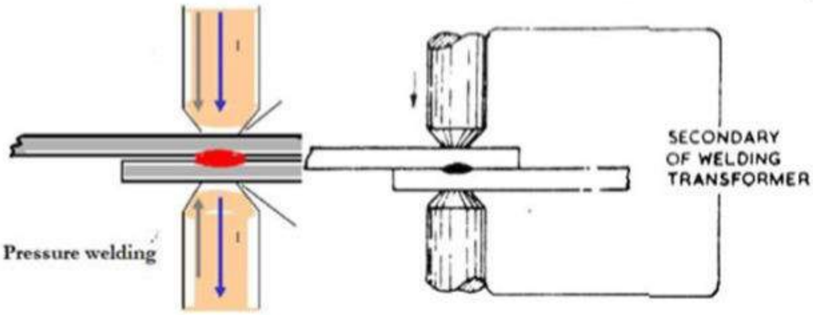
Gas Tungsten Arc welding


Gas nozzle
Consumable electrode
Contact tube
Gas shield
Arc
Weld metal
Parent metal
Weld pool

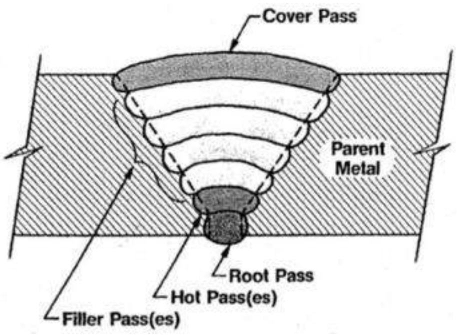
MIG welding

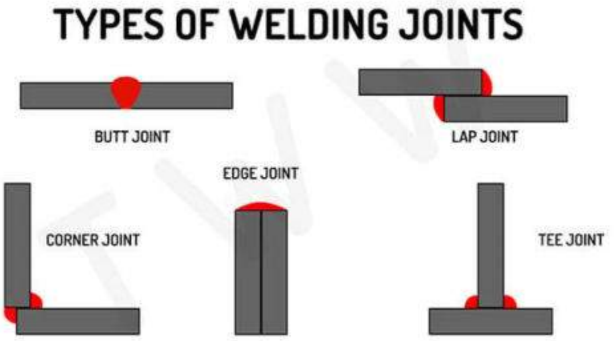

Welding Torch
Pressure Regulators
Weld Joint Formation
Needle Valves
Oxygen Cylinder (Black)
Work Piece
Fuel Gas Cylinder (Black)

Gas Welding


Pressure welding
SECONDARY OF WELDING TRANSFORMER

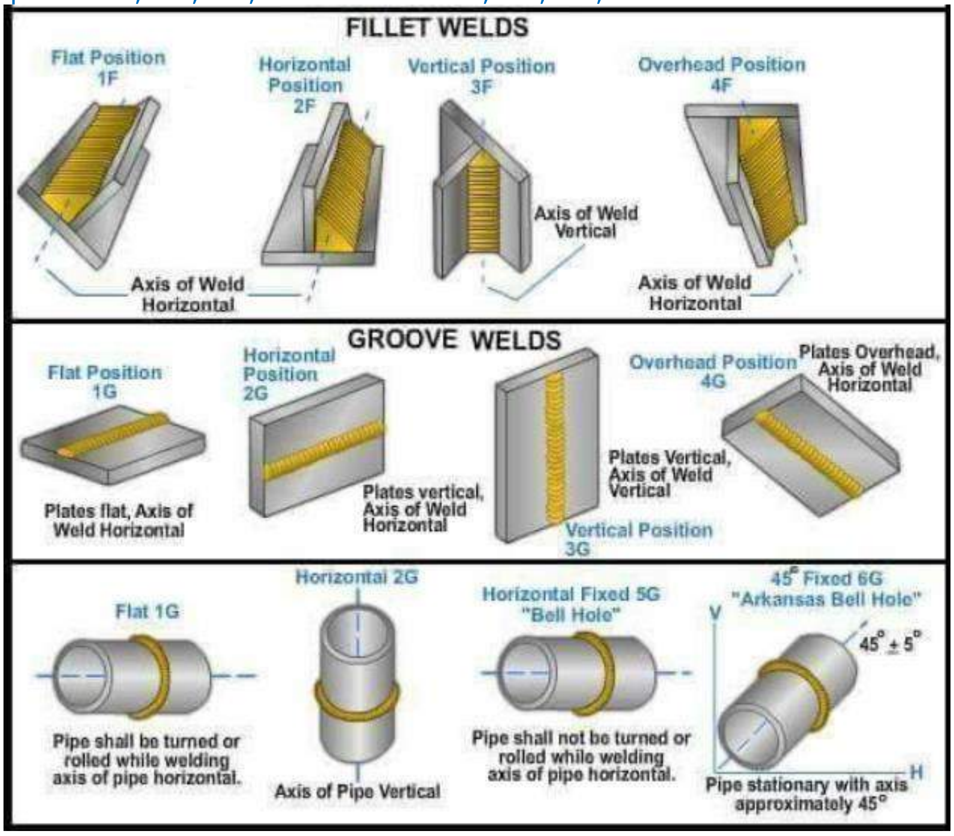
- **Write the weld layers?** a ) Root b ) Hot Pass c ) Fill d ) Cap / cover


Cover Pass
Parent Metal
Root Pass
Hot Pass(es)
Filler Pass(es)


TYPES OF WELDING JOINTS
BUTT JOINT
LAP JOINT
EDGE JOINT
CORNER JOINT
TEE JOINT

- **Welding Position**

  Pipe – 1GR, 2G, 5G, 6G & Plate – 1G, 2G, 3G, 4G


FILLET WELDS
Flat Position 1F
Horizontal Position 2F
Vertical Position 3F
Overhead Position 4F
Axis of Weld Horizontal
Axis of Weld Vertical
Axis of Weld Horizontal
GROOVE WELDS
Flat Position 1G
Horizontal Position 2G
Overhead Position 4G
Plates Overhead, Axis of Weld Horizontal
Plates flat, Axis of Weld Horizontal
Plates vertical, Axis of Weld Horizontal
Plates Vertical, Axis of Weld Vertical
Vertical Position 3G
Flat 1G
Horizontal 2G
Horizontal Fixed 5G "Bell Hole"
45° Fixed 6G "Arkansas Bell Hole"
V
45° ± 5°
H
Pipe shall be turned or rolled while welding axis of pipe horizontal.
Axis of Pipe Vertical
Pipe shall not be turned or rolled while welding axis of pipe horizontal.
Pipe stationary with axis approximately 45°

**PIPE:-**

1G: - A Pipe is Horizontal Position and weld is a vertical position.
2G: - A Pipe is Vertical Position and weld is Horizontal Position
5G: - A Pipe is Horizontal Position and weld is Vertical Position
6G: - A Pipe is a $45^0$ Position

**PLATE:-**

1G: - Plate is Horizontal and weld is Horizontal
2G: - Plate is Vertical and weld is Horizontal
3G: - Plate is Vertical and weld is Vertical
4G: - A Plate is in Overhead Position weld is Horizontal Position

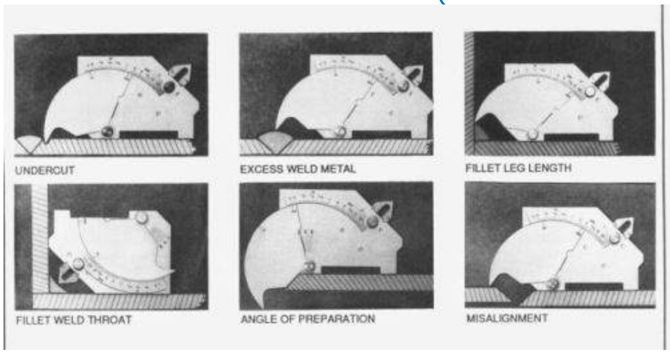
## TWO REASONS FOR HAVING VENT HOLE ON REINFORCING PAD OF BRANCH CONNECTION:

RF Pads are plates used to reinforce components and/or nozzles by increasing thickness local to the component in high stressed zones. These are made from the same size and material as the pipe header to which they are welded.

- To reveal leakage in the weld between branch and header.
- To allow venting during welding and heat treatment.

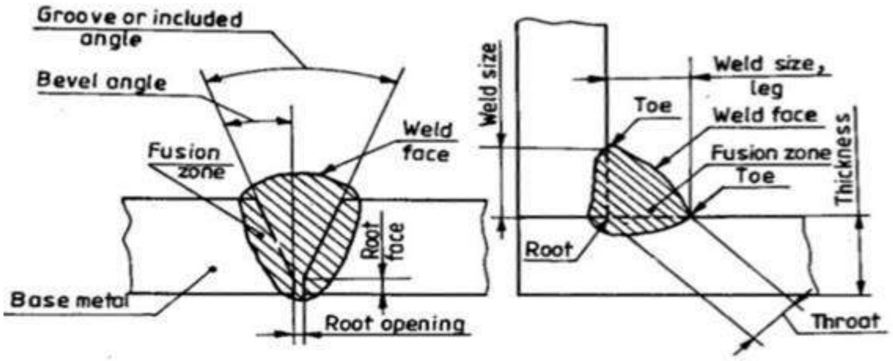
## ACCEPTANCE CRITERIA FOR INSPECTION OF 6" DIA, SCH. 40 BUTT WELD JOINT (exmp):

a) Bevel Angle ……………………… 37.5 deg. (tolerance ± 2.5 deg)
b) Root Gap………………………….. 1.6mm (tolerance ± 0.8mm)
c) Internal Alignment (Hi- Lo)…1.6 mm below.
d) Root Face…………………………..1.6mm (tolerance ± 0.8mm)


UNDERCUT
EXCESS WELD METAL
FILLET LEG LENGTH
FILLET WELD THROAT
ANGLE OF PREPARATION
MISALIGNMENT

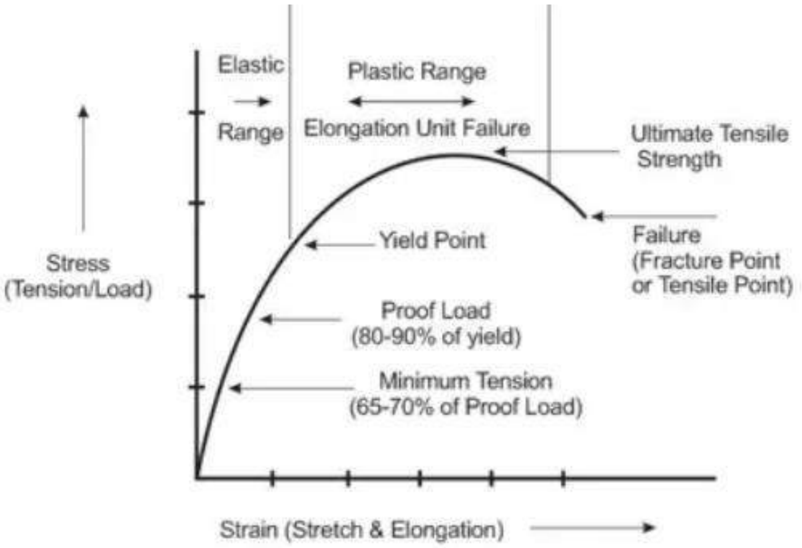
- **What are the Weldment Terms?** Weld Face , Weld Root , Fusion Zone , Fusion Boundary ,Heat Affected Zone (HAZ) , Weld Toes , Weld Width

## Basic Types of Joints & Terms



(a)–Butt weld (b)–Fillet weld

- **What is the difference between tensile test & yield test?**
  - A tensile test is a test to obtain an accurate assessment of the strength and ductility of a material or a weld.
  - A yield test is to obtain the strength at some arbitrary amount of extension under load or a permanent plastic strain (offset).



Tensile Stress-Strain Diagram

- **What is the procedure for application of wrapping and coating?**

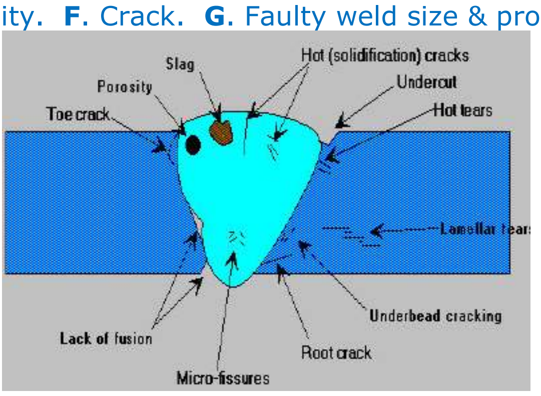
  **A**. Prior to application of wrapping & coating, the surface of pipe should be made free from all loose Mill scale, dirt, rust, grease, moisture and other foreign material. This is achieved by blast cleaning to grade Sa 2 ½.
  **B**. The pipe exterior surface or blast surface shall be coated with primer within four hours of shot blasting. The primer shall not be applied when the pipe surface temperature is below 7°C and above 70°C. When moisture is present on the surface, the same is heated for sufficient time to dry the surface.
  **C**. The pipe after priming shall be coated with two-flood coat of hot enamel incorporating the simultaneous application of inner & outer wrapping.

- **What is tack weld?**
  Tack weld is the temporary weld to maintain joint alignment. All tack welds shall be made by qualified welders. Recommended tack thickness is 3.2 – 4.8mm & length is 12.5 - 25.4 mm. the minimum number of tack welds for 3.5 inch and below are 3 equally spaced tacks. Above 3.5 inch 4 equally spaced tacks.

- **What type of cutting used is SS? Types of Grinding wheel and how to identify them?**
  - Plasma arc cutting and grinding wheel
  - Types for grinding wheel are: Iron oxide, zirconium, Aluminum oxide.
  - Identification by color coding.(blue)

- **What are the common welding defects?**

**A**. Lack of penetration. **B**. Lack of fusion. **C.** Undercut. **D**. Slag inclusion.
**E**. Porosity. **F**. Crack. **G**. Faulty weld size & profile. **H**. Distortion


Slag
Hot (solidification) cracks
Porosity
Undercut
Toe crack
Hot tears
Lamellar tears
Underbead cracking
Lack of fusion
Root crack
Micro-fissures

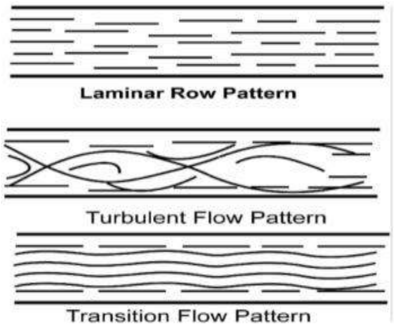
- **FLOW THROUGH PIPE LINES** types of fluid flow take place in pipelines:

**Laminar Flow :** Flow at lower velocities is smooth and streamlines and is called as **laminar flow.**
**Turbulent Flow:** When fluid flow velocities are very high, cross flows take place giving the fluid a fluctuating nature or turbulence and such a flow is called as turbulent flow.

**Reynolds No = Diameter of pipe × Velocity of fluid × Density of fluid / viscosity of fluid**

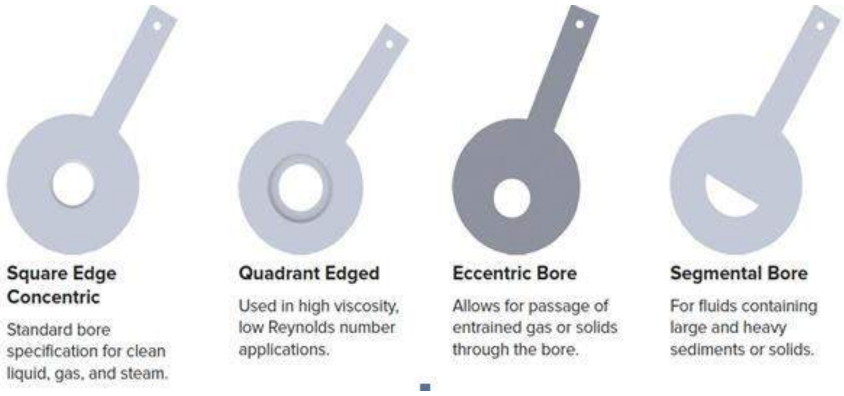
- ✓ Flow will be **Laminar** if Reynolds no. is ≤ **2100,**
- ✓ Flow will be **Turbulent** if Reynolds no. is ≥ **4000,**
- ✓ Flow will be **Transitional** if Reynolds no. is between **2100 & 4000.**

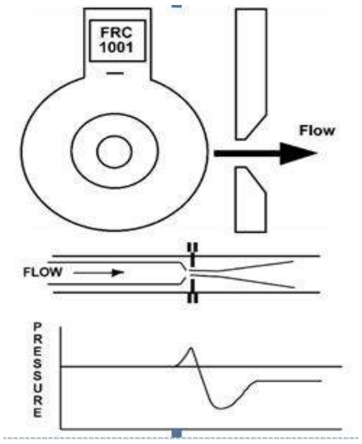
**Reynolds no. is a pure number without any unit.**


Laminar Row Pattern
Turbulent Flow Pattern
Transition Flow Pattern

**Types of Orifice Plates:** Concentric Orifice, Eccentric Orifice & Segmental Orifice

**ORIFICE PLATE:** Is a flat disc with a precisely made hole at its center, it offers a well-defined obstruction to flow when inserted in a line. The resistance of the orifice sets up a pressure difference in the fluid either side of the plate, which can be used to measure the rate of flow.


Square Edge Concentric
Standard bore specification for clean liquid, gas, and steam.
Quadrant Edged
Used in high viscosity, low Reynolds number applications.
Eccentric Bore
Allows for passage of entrained gas or solids through the bore.
Segmental Bore
For fluids containing large and heavy sediments or solids.


FRC 1001
Flow
FLOW
PRESSURE

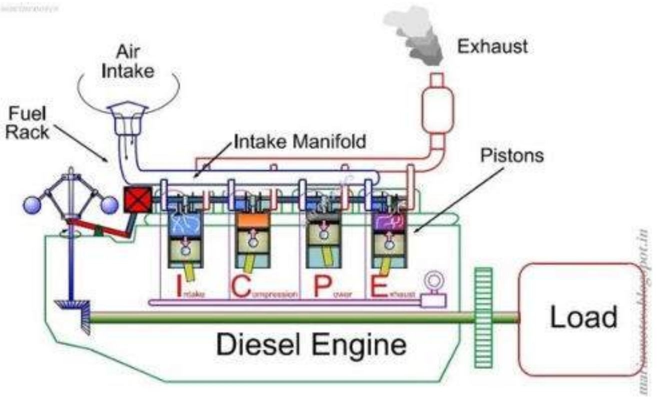
Orifice means sudden reduction in area. Just like nozzle, when high pressured fluid flows through the sudden reduction area then the pressure will be reduced

- **What item to be checked during orifice flange fabrication?**

Flush Grinding of butt welds of the orifice flange inside and seal welding of orifice tapping Pipes, check Visual and PT / MT.

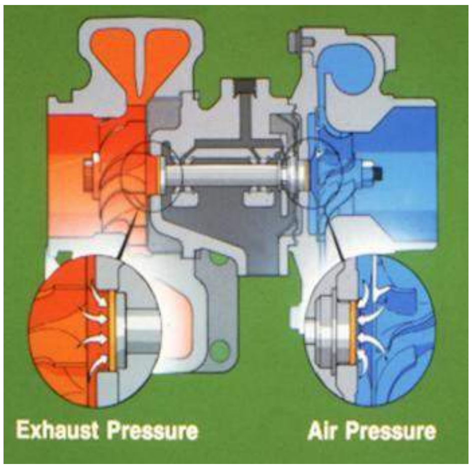
- **What is the working principle of a Governor in a diesel engine?**

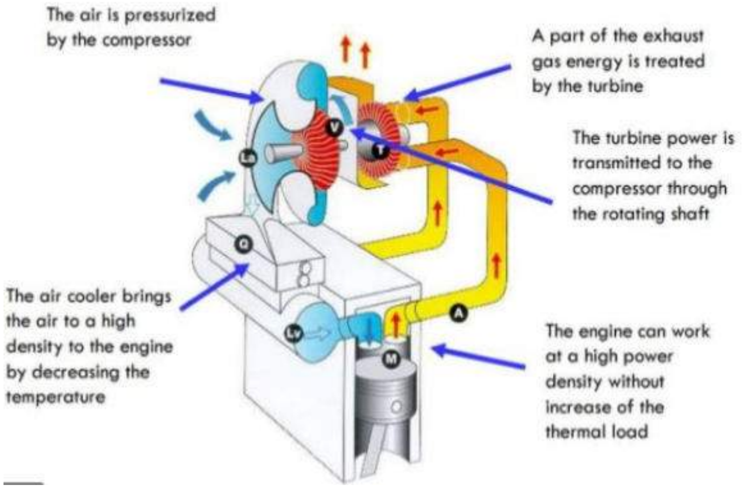
A vital component of any diesel engine system is the governor, which limits the speed of the engine by controlling the rate of fuel delivery. The governor provides the engine with the feedback mechanism to change speed as needed and to maintain a speed once reached. A governor is essentially a speed-sensitive device, designed to maintain a constant engine speed regardless of load variation.


Air Intake
Exhaust
Fuel Rack
Intake Manifold
Pistons
I Intake
C Compression
P Power
E Exhaust
Load
Diesel Engine

- **What is the working principle of a turbocharger in a diesel engine?**

  A **turbocharger** or **turbo** (mixing/spinning) is a centrifugal compressor powered by a high speed turbine that is driven by an engine's exhaust gases. Its benefit lies with the compressor increasing the mass of air entering the engine (forced induction), thereby resulting in greater performance (for either, or both, power and efficiency). They are popularly used with internal combustion engines (e.g., four-stroke engines like Otto cycles and Diesel cycles).


Exhaust Pressure
Air Pressure


The air is pressurized by the compressor
A part of the exhaust gas energy is treated by the turbine
The turbine power is transmitted to the compressor through the rotating shaft
The air cooler brings the air to a high density to the engine by decreasing the temperature
The engine can work at a high power density without increase of the thermal load

- **What is the difference between cast and wrought iron?**

Actually, the basic **distinction between** the two is simple: **Cast iron** is **iron** that has been melted, poured into a mold, and allowed to cool. **Wrought iron** is **iron** that has been heated and then worked with tools. In fact, the term "**wrought**" derived from the past participle of the word "worked."

- **What is Pressure Drop (ΔP)?**

A fluid always moves from a high pressure point to low pressure point. During this motion of fluid its pressure decreases or drops due to friction in the fluid flow path. The difference in the pressure of fluid at two different points inside a flowing fluid is called pressure difference or pressure drop. A fluid flow takes place only when there is ΔP (Delta-P) or pressure drop across two points. When a fluid starts moving, it gains speed or velocity. Pressure drop in the fluid due to friction depends on pipe length, pipe diameter, internal roughness of the pipe, flow rate of fluid, vviscosity of fluid , type of valves, Fitting, equipment through which fluid flow takes place.

**Units:** ΔP is expressed in "bar" ---Fluid velocity is expressed as "M/S"

**Throttling of Valves**

When valves are throttled, the pressure drop increases for the flowing fluids. Hence undue throttling should be avoided for valves.

**Throttling has following disadvantages:**

1. Increases the energy consumption, as pumping equipment has to work more to compensate for the pressure drop caused by throttling
2. Erosion effects are experienced across the valves

**Equalizing Pressure across The Valves**

When there is a differential pressure across a valve, the force acting on the valve seat is maximum, thereby lot of efforts are required to open the valve. It is good practice to first equalize the pressure across the valve, thereby creating nil delta pressure across the valve that can be easily operated thereafter. Equalizing means are sometimes provided, in terms of a small bypass valve across the main valve.

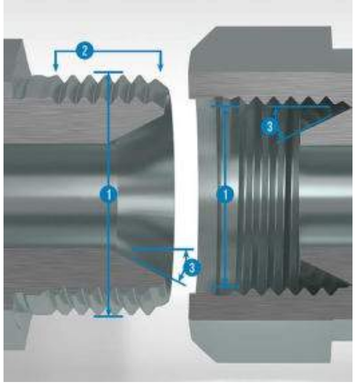
**What is the difference between S.S to EN 8**

SS- Stainless steel – corrosion resistant

En- Medium carbon steel –MAGNETIC material

**What is the temperature of space?** The temperature in space is approximately 2.725 Kelvin. That means the universe is generally just shy of three degrees above absolute zero , the temperature at which molecules themselves stop moving. That's almost -270 degrees Celsius, or -455 Fahrenheit.

- **How to Measure Threads**
  1.) First, use a combination O.D./I.D. caliper to measure the thread diameter. Note: The threads of a used fitting can become worn and distorted, so the measurements may not be exact.

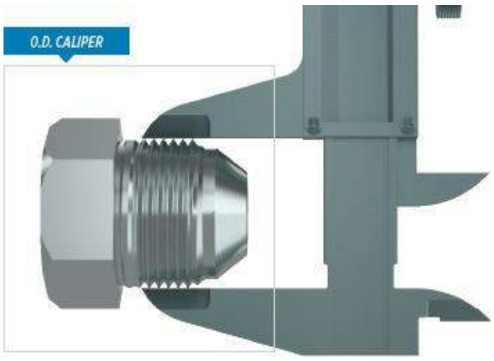


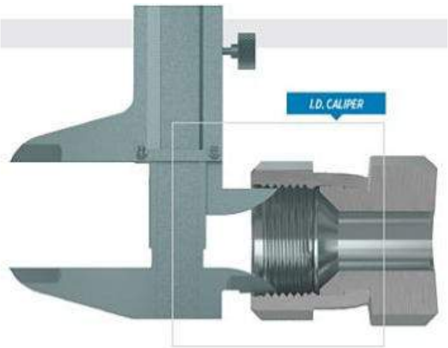
2.) Second, use a thread pitch gauge to identify the number of threads per inch. For metric connections, measure the distance between threads. Place the gauge on the threads until it fits snugly; match your measurements with a thread chart.

3.) Third, if the port is angled, determine the seat angle by using a gauge on the sealing surface. The centerline of the fitting and the gauge must be parallel.

### Measuring Tools

By using a combination of three tools, identifying connectors is easy to do. Using an I.D./ O.D. caliper, thread pitch gauge and seat angle gauge allow you to make accurate measurements of most connections. Many thread ID calipers provide both a caliper and a seat angle gauge in one tool.





The **I.D./O.D. caliper** is used to measure the O.D. of a male thread and I.D. of a female thread. (Important: When matching gauge measurements to thread charts keep in mind that threads on connections that have been in-service may be worn and distorted from use, causing inexact comparison to the thread tables.

For English, British and other European threads the thread pitch gauge measures the threads per inch. However, for metric threads the gauge will identify the distance between the threads.

The **seat angle gauge** is used by placing the gauge angle on the sealing surface. The centerline of the fitting end and the gauge should be parallel. In the English system the thread size and pitch (number of threads per inch) are given, along with the thread type.

### Measuring Threads

Using the **thread pitch gauge**, align the gauge on the threads and make sure it is snug. Match the measurement to the a thread chart. Then measure the thread diameter with the I.D./ O.D. caliper.

### Measuring Sealing Surface Angles

Female connections are measured by inserting the ID portion of the gauge into the connection on the sealing surface. Be sure the centerlines of the connection and gauge are parallel to identify the correct angle. For male flare type connections, place the gauge on the sealing surface to establish the measurement. Again, be sure the centerlines of the connection and gauge are parallel to identify the correct angle.

### What is heat treatment and why is it done?

Heat treatment can be defined as a combination of processes or operations in which the heating and cooling of a metal or alloy is done in order to obtain desirable characteristics without changing the compositions. Some of the motives or purpose of heat treatment are as follows:

1) In order to improve the hardness of metals.
2) For the softening of the metal.
3) In order to improve the machinability of the metal.
4) To change the grain size.
5) To provide better resistance to heat, corrosion, wear etc.

Heat treatment is generally performed in the following ways:
Normalizing , Annealing ,Spheroidising ,Hardening ,Tempering ,Surface or case hardening

### Why should a chain drive be used over a belt or rope driven drive? State pro`s and con`s?

**The advantages of using a chain drives are:**

1) In a chain drive no slip occurrence takes place.
2) The chains take less space as compared to rope or belts as they are made of metal and offer much strength.
3) The chain drives can be used at both short and long ranges and they offer a high level of transmission efficiency.
4) Chain drives can transmit more load and power as compared to belts.
5) A very high speed ratio can be maintained in one step of chain drives.

**Some of the cons of using a chain drive are:**

1) The cost of producing chain drives is higher as compared to that of belts.
2) The chain drives must be serviced and maintained at regular intervals and henceforth their cost of ownership is high comparatively.

### What are the different types of brakes and explain them briefly?

Brakes can be classified on the basis of their medium used to brake, they are as follows:

**Hydraulic Brakes:** These brakes as their name suggest use a fluid medium to push or repel the brake pads for braking.

**Electric Brakes:** These brakes use electrical energy to deplete or create a braking force.

Both the above types of breaks are used primarily for applications where a large amount of energy is to be transformed.

**Mechanical Brakes:** They can be further classified on the basis of the direction of their acting force:

Radial Brakes: As their names suggests the force that acts on the brakes is of radial direction. They can further be classified into internal and external blades.

Axial Brakes: In these types of brakes the braking force is acting in an axial direction as compared to radial brakes.

### What is the difference between Technology and Engineering?

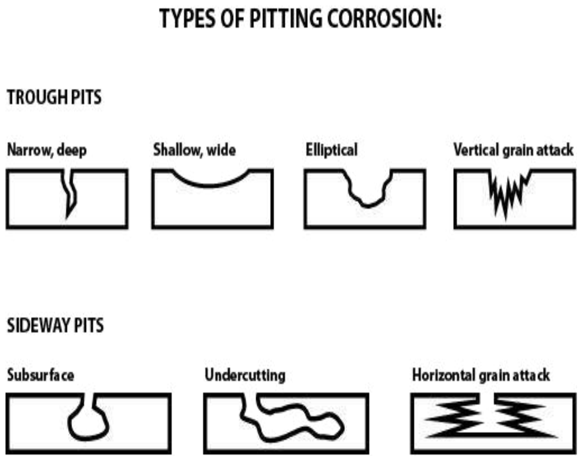
Engineering is application of science. Technology shows various methods of Engineering.

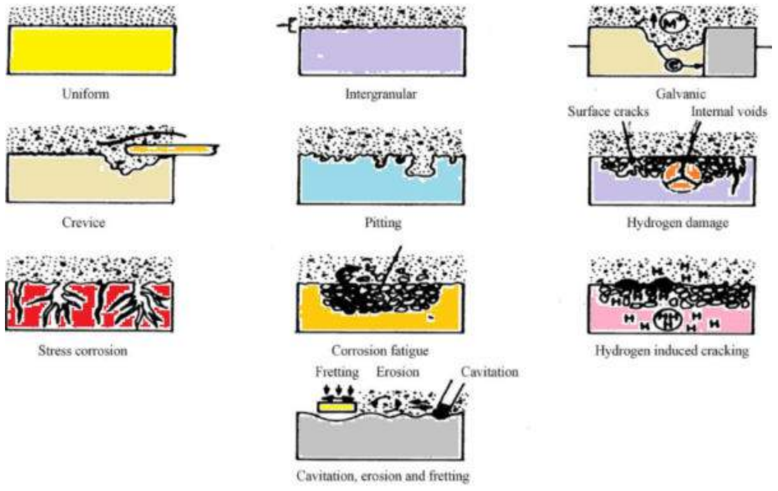
- **What is Mechanical Engineering?**

  Mechanical engineering is a branch of engineering in which we apply physics laws along with material science to accelerate the human process.

### What is pitting? How it is caused?

Non uniform corrosion over the entire metal surface, but occurring only in small pits is called pitting. It is caused by lack of uniformity in metal.


TYPES OF PITTING CORROSION:
TROUGH PITS
Narrow, deep
Shallow, wide
Elliptical
Vertical grain attack
SIDEWAY PITS
Subsurface
Undercutting
Horizontal grain attack

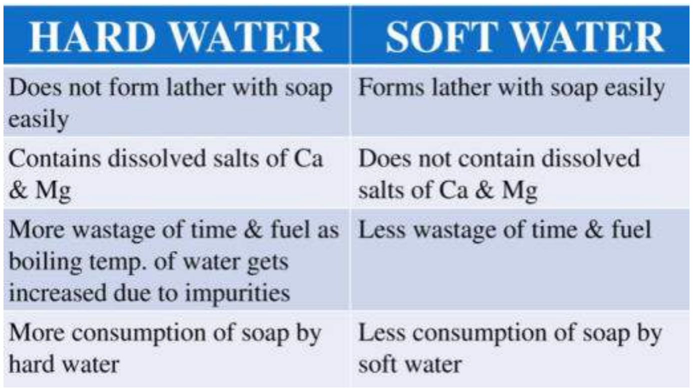

Uniform
Intergranular
Galvanic
Surface cracks
Internal voids
Crevice
Pitting
Hydrogen damage
Stress corrosion
Corrosion fatigue
Hydrogen induced cracking
Fretting
Erosion
Cavitation
Cavitation, erosion and fretting

### Which two elements in feed water can cause corrosion of tubes and plates in EXCHANGER?

Acid and oxygen in feed water lead to corrosion

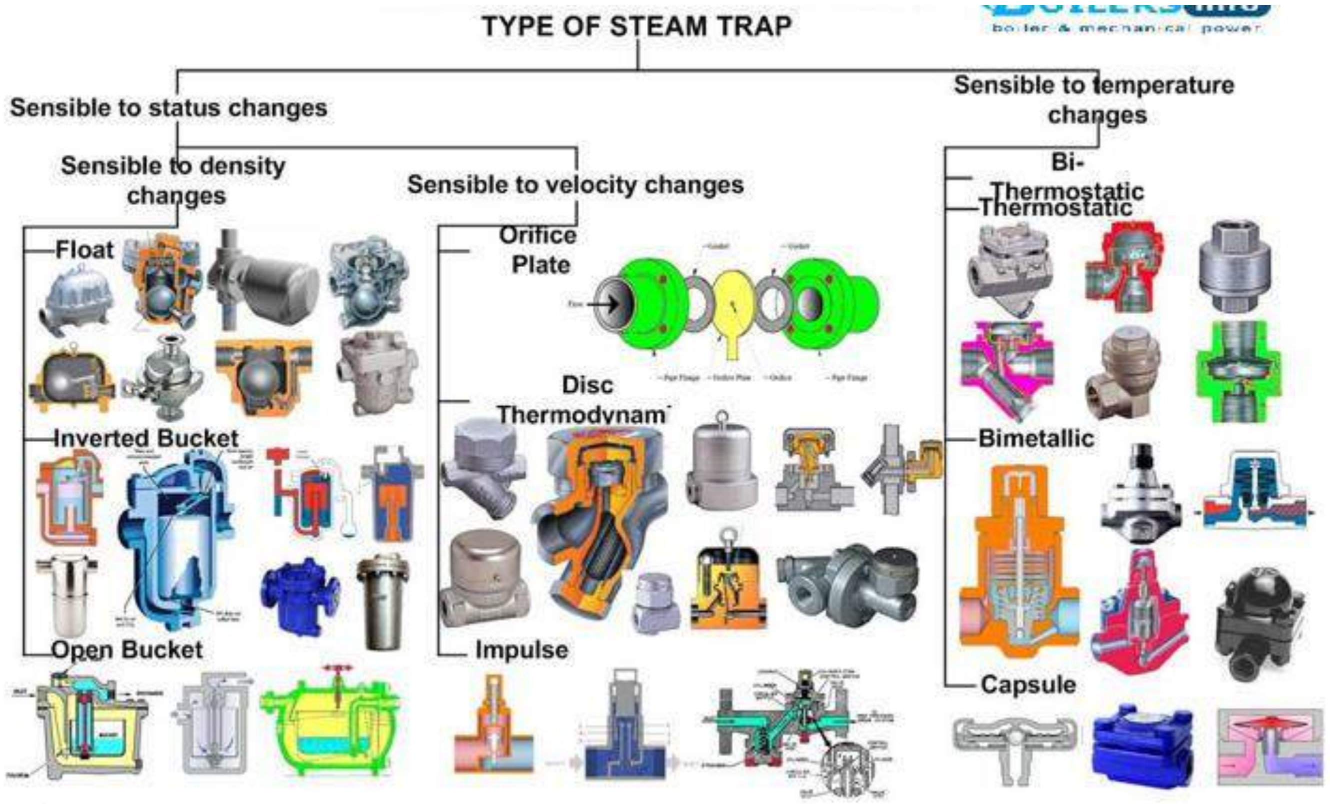
**What is the difference between hard water and soft water?**

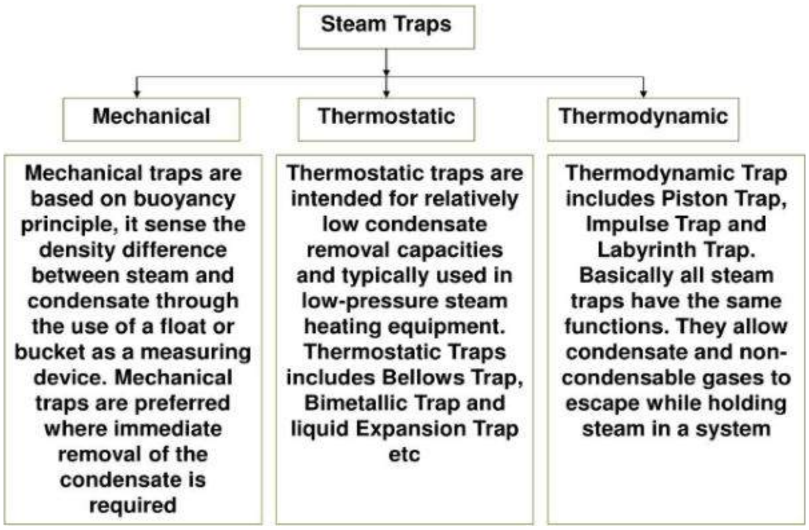
Hard water contains excess of scale forming impurities and soft water contains very little or no scale forming substances.



| HARD WATER | SOFT WATER |
|---|---|
| Does not form lather with soap easily | Forms lather with soap easily |
| Contains dissolved salts of Ca & Mg | Does not contain dissolved salts of Ca & Mg |
| More wastage of time & fuel as boiling temp. of water gets increased due to impurities | Less wastage of time & fuel |
| More consumption of soap by hard water | Less consumption of soap by soft water |

## Steam trap:


TYPE OF STEAM TRAP
boiler & mechanical power
Sensible to status changes
Sensible to temperature changes
Sensible to density changes
Sensible to velocity changes
Float
Orifice Plate
Bi-Thermostatic
Thermostatic
Disc Thermodynamic
Inverted Bucket
Bimetallic
Open Bucket
Impulse
Capsule


Steam Traps
Mechanical
Thermostatic
Thermodynamic

Mechanical traps are based on buoyancy principle, it sense the density difference between steam and condensate through the use of a float or bucket as a measuring device. Mechanical traps are preferred where immediate removal of the condensate is required

Thermostatic traps are intended for relatively low condensate removal capacities and typically used in low-pressure steam heating equipment. Thermostatic Traps includes Bellows Trap, Bimetallic Trap and liquid Expansion Trap etc

Thermodynamic Trap includes Piston Trap, Impulse Trap and Labyrinth Trap. Basically all steam traps have the same functions. They allow condensate and non-condensable gases to escape while holding steam in a system

A **steam trap** is a device used to discharge condensate and non condensable gases with a negligible consumption or loss of live steam. Most steam traps are nothing more than automatic valves. They open, close or modulate automatically. Others, like venturi traps, are based on turbulent flows to obstruct the steam flow.

**The three important functions of steam traps are:**

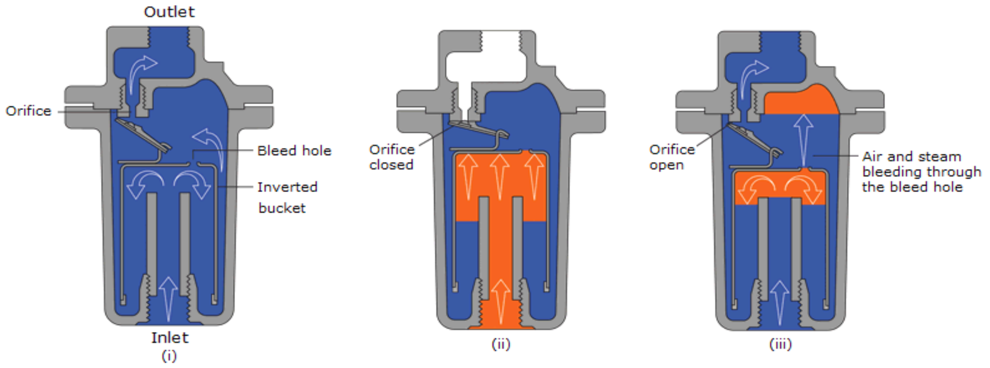
1. Discharge condensate as soon as it is formed.
2. Have negligible steam consumption.
3. Have the capability of discharging air and other non-condensable gases.

**Basic operation**

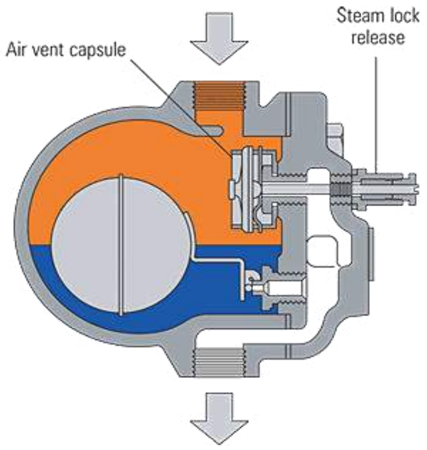
The best and simplest form of steam trap is a disc or short solid pipe nipple with a small hole drilled through it installed at the lowest point of the equipment/piping. Since steam condensate will collect at the lowest point and live steam is as about 1200 greater in volume than this hot liquid, condensate is effectively removed and steam is blocked. Mechanical steam traps basically open when condensate needs to be removed, and close when there is only steam present. Steam traps work best when sized specifically for the application they are used on. Generally it is better to over size as they will still discharge condensate when present and close or obstruct for live steam. However an over sized steam trap will wear quickly, waste energy (use steam), and if drastically over sized can cause process issues.

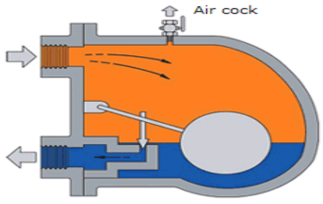
**Types**

1. **Mechanical traps**. They have a float that rises and falls in relation to condensate level and this usually has a mechanical linkage attached that opens and closes the valve. Mechanical traps operate in direct relationship to condensate levels present in the body of the steam trap. **Inverted bucket** and **float traps** are examples of mechanical traps.

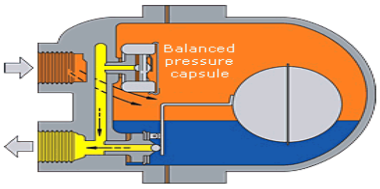

Outlet
Orifice
Bleed hole
Inverted bucket
Inlet
(i)
Orifice closed
(ii)
Orifice open
Air and steam bleeding through the bleed hole
(iii)

2. **Temperature traps**. They have a valve that is driven on / off the seat by either expansion / contraction caused by temperature change. They differ from mechanical traps in that their design requires them to hold back some condensate waiting for it to cool sufficiently to allow the valve to open. In most circumstances this is not desirable as condensate needs to be removed as soon as it is formed. **Thermostatic traps**, **Bi-Thermostatic traps** and **bimetallic traps** are examples of temperature operated traps.


Air vent capsule
Steam lock release

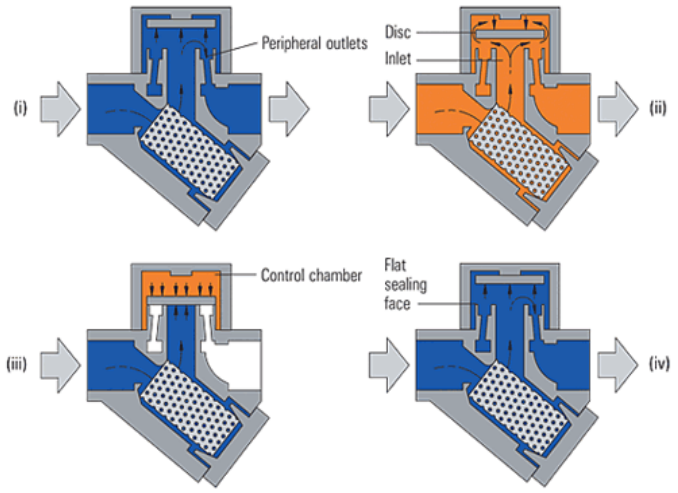


Float trap with air cock

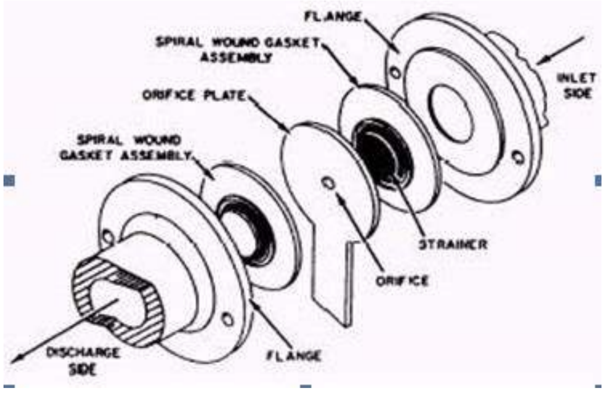

Balanced pressure capsule

Float trap with thermostatic air vent

3. **Thermodynamic (TD) traps**. Thermodynamic traps work on the difference in dynamic response to velocity change in flow of compressible and incompressible fluids. As steam enters, static pressure above the disk forces the disk against the valve seat. The static pressure over a large area overcomes the high inlet pressure of the steam. As the steam starts to condense, the pressure against the disk lessens and the trap cycles. This essentially makes a TD trap a "time cycle" device: it will open even if there is only steam present, this can cause premature wear. If non condensable gas is trapped on top of the disc, it can cause the trap to be locked shut.

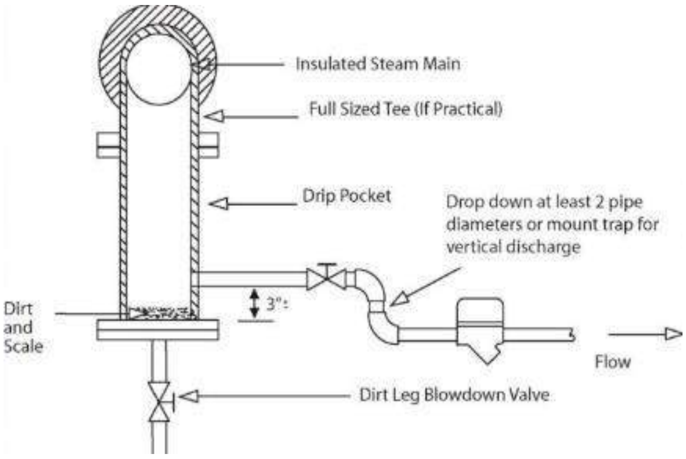

(i)
Peripheral outlets
Disc
Inlet
(ii)
(iii)
Control chamber
Flat sealing face
(iv)

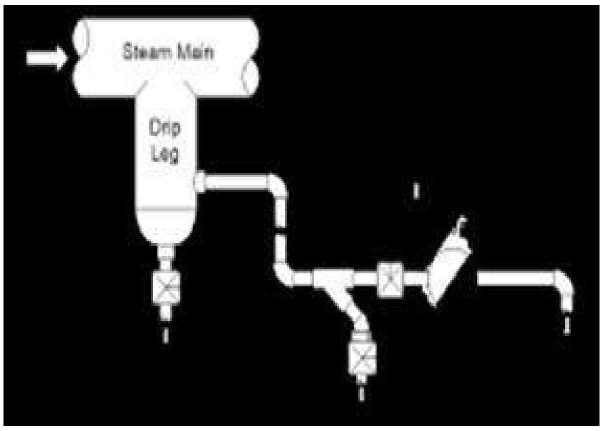
4. **Venturi (orifice) traps**. This type works in a turbulent two-phase flow regime. Internally it consists of a venturi type valve with a certain shape. Condensate is fully discharged while eventual steam also tries to pass the venturi. But while traversing the venturi towards the low pressure zone the steam expands and chokes the throughput together with the slow condensate. Because of this, the amount of live steam escaping the orifice is negligible.


FLANGE
SPIRAL WOUND GASKET ASSEMBLY
ORIFICE PLATE
SPIRAL WOUND GASKET ASSEMBLY
INLET SIDE
STRAINER
ORIFICE
DISCHARGE SIDE
FLANGE

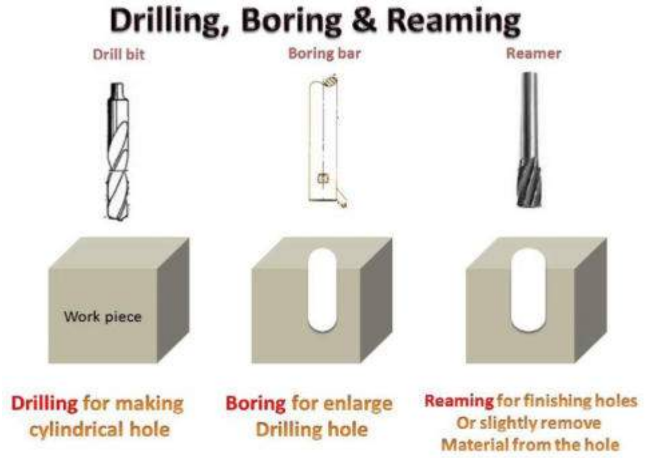
- **Why do we provide Drip Leg in Steam Line?**

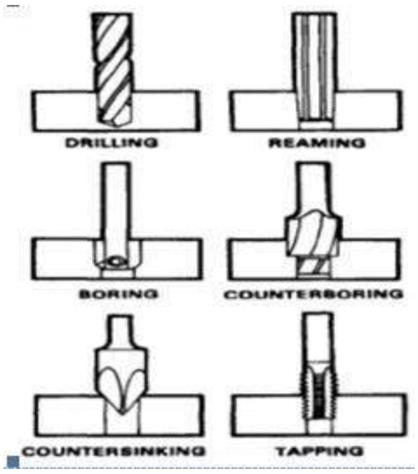
To remove condensate when there is a rise of same in the pipe along the flow direction. If drip leg is not provided in steam line, the condensate which forms inside the pipe will result in Water Hammer effect causing damage to piping system.


Insulated Steam Main
Full Sized Tee (If Practical)
Drip Pocket
Drop down at least 2 pipe diameters or mount trap for vertical discharge
3"±
Dirt and Scale
Flow
Dirt Leg Blowdown Valve


Steam Main
Drip Leg

**Difference between drilling, reaming & boring:**


Drilling, Boring & Reaming
Drill bit
Boring bar
Reamer
Work piece
Drilling for making cylindrical hole
Boring for enlarge Drilling hole
Reaming for finishing holes Or slightly remove Material from the hole

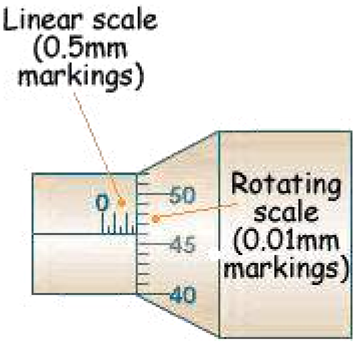

DRILLING
REAMING
BORING
COUNTERBORING
COUNTERSINKING
TAPPING

## The micrometer screw gauge

The micrometer screw gauge is used to measure even smaller dimensions than the vernier callipers. The micrometer screw gauge also uses an auxiliary scale (measuring hundredths of a millimeter) which is marked on a rotary thimble. Basically it is a screw with an accurately constant pitch (the amount by which the thimble moves forward or backward for one complete revolution). The micrometers have a pitch of 0.50 mm (two full turns are required to close the jaws by 1.00 mm). The rotating thimble is subdivided into 50 equal divisions. The thimble passes through a frame that carries a millimeter scale graduated to 0.5 mm. The jaws can be adjusted by rotating the thimble using the small ratchet knob. This includes a friction, clutch which prevents too much tension being applied. The thimble must be rotated through two revolutions to open the jaws by 1 mm.

- **Outside micrometer** typically used to measure wires, spheres, shafts and blocks.
- **Inside micrometer** used to measure the diameter of holes.
- **Depth micrometer** measures depths of slots and steps.

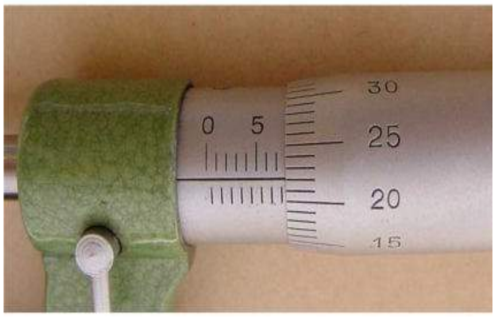
Place the wire between the anvil and spindle end .Rotate the thimble until the wire is firmly held between the anvil and the spindle. The rachet is provided to avoid excessive pressure on the wire. It prevents the spindle from further movement - squashing the wire!.


Linear scale (0.5mm markings)
0
50
45
40
Rotating scale (0.01mm markings)

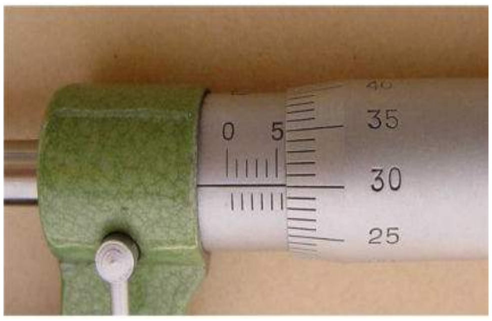
To take a reading first look at the main scale. This has a linear scale reading on it. The long lines are every millimeter the shorter ones denote half a millimeter in between.

On the diagram this reading is 2.5 mm, Now look at the rotating scale. That denotes 46 divisions , each division is 0.01mm so we have 0.46mm from this scale. The diameter of the wire is the sum of these readings: 2.5 + 0.46 = **2.96 mm**

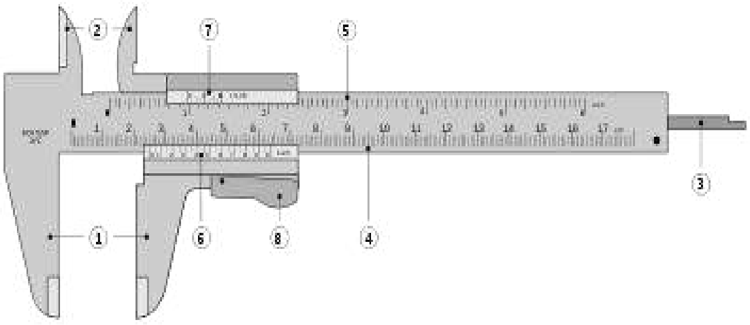
**Examples:** Imagine that the scales have come to the positions as shown in the figure below, after the jaws are kept around the object. The lock can be used to assure that readings don’t change due to the movement of the thimble. In the figure, it can be seen that the marking on the main scale which is just to the left of the thimble is 7 mm. However, the half scale division that is visible below the main scale shouldn’t be neglected and thus the reading on the main scale will be 7.5mm. For the auxiliary scale reading, it is noted that the 22nd division on the thimble scale matches with the main scale. Thus the thimble scale reading would be 0.22 mm. The final reading will be the addition of these two readings i.e. 7.5 + 0.22 = 7.72 mm.



Let’s take one more example to understand it properly. Suppose the scales came to the positions shown in the figure. The main scale reading would be the marking that is fully visible immediately to the left of the thimble, i.e. 5.5 mm. For the auxiliary reading, the 30th division of the thimble matches with the main scale and thus its reading will be 0.30 mm. The final reading will be the addition of the readings of both the scale i.e. 5.5 + 0.30 = 5.80 mm.



**Vernier caliper** is a device used to measure the distance between two opposing sides of an object. A caliper can be as simple as a compass with inward or outward-facing points. The tips of the caliper are adjusted to fit across the points to be measured, the caliper is then removed and the distance read by measuring between the tips with a measuring tool, such as a ruler.



Parts of a vernier caliper:

1. **Outside jaws**: used to measure external diameter or width of an object
2. **Inside jaws**: used to measure internal diameter of an object
3. **Depth probe**: used to measure depths of an object or a hole
4. **Main scale**: scale marked every mm
5. **Main scale**: scale marked in inches and fractions
6. **Vernier scale** gives interpolated measurements to 0.1 mm or better
7. **Vernier scale** gives interpolated measurements in fractions of an inch
8. **Retainer**: used to block movable part to allow the easy transferring of a measurement

**How to use and read a vernier caliper**？ An ordinary **vernier caliper** has jaws you can place around an object, and on the other side jaws made to fit inside an object. These secondary jaws are for measuring the inside diameter of an object. Also, a stiff bar extends from the caliper as you open it that can be used to measure depth.

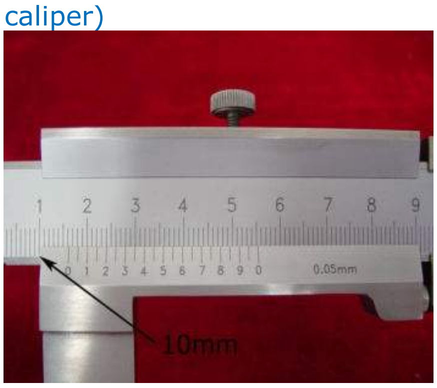
**The basic steps are as follows:**

1. Preparation to take the measurement, loosen the locking screw and move the slider to check if the vernier scale works properly. Before measuring, do make sure the caliper reads 0 when fully closed. If the reading is not 0, adjust the caliper's jaws until you get a 0 reading. If you can't adjust the caliper, you will have to remember to add /to subtract the correct offset from your final reading. Clean the measuring surfaces of both vernier caliper and the object, then you can take the measurement.

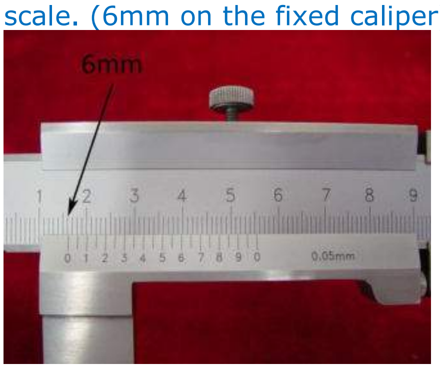
2. Close the jaws lightly on the item which you want to measure. If you are measuring something round, be sure the axis of the part is perpendicular to the caliper. Namely, make sure you are measuring the full diameter. An ordinary caliper has jaws you can place around an object, and on the other side jaws made to fit inside an object. These secondary jaws are for measuring the inside diameter of an object. Also, a stiff bar extends from the caliper as you open it that can be used to measure depth.

3. How to read the measured value:

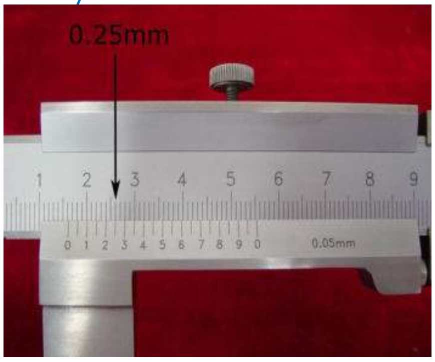
a) Read the centimeter mark on the fixed scale to the left of the 0-mark on the vernier scale. (10mm on the fixed caliper)



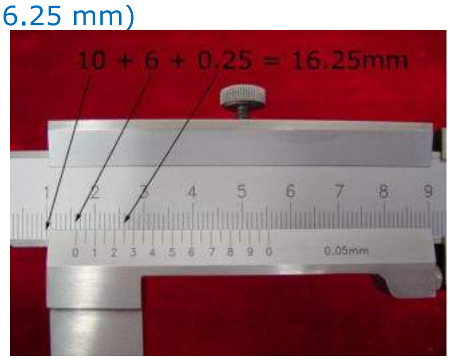
b). Find the millimeter mark on the fixed scale that is just to the left of the 0-mark on the vernier scale. (6mm on the fixed caliper)



c). Look along the ten marks on the vernier scale and the millimeter marks on the adjacent fixed scale, until you find the two that most nearly line up. (0.25mm on the vernier scale)



d). To get the correct reading, simply add this found digit to your previous reading. (10mm + 6mm + 0.25mm= 16.25 mm)



4. Maintenance: Clean the surface of the vernier caliper with dry and clean cloth (or soaked with cleaning oil) and stock in a dry environment if it stands idle

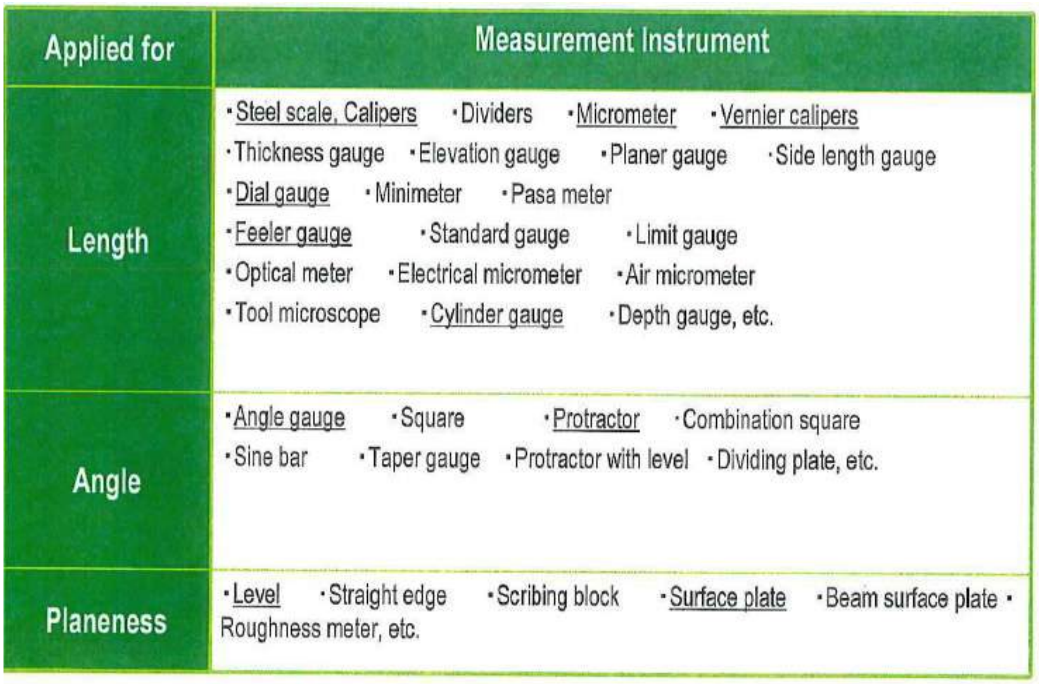
- **How to analyze the best accuracy to micrometer than Vernier?**

1) Micrometer have a rotary handle and whereas Vernier have a slider scale.
2) Micrometer for measuring diameters and Vernier for inside outside diameter as well as depth.
3) A typical micrometer screw gauge has a maximum accuracy of +or-0.01mm reading whereas a Vernier caliper has a typical maximum accuracy of +or 0.1mm reading.
4) Vernier Has Least Count of 0.02 mm (Least count is minimum unit that can be measured)
Micrometer comes with Least Count of 0.01 mm. so obviously micrometers are more accurate. One benefit of Micrometer is that, they come with THIMBLE for uniform pressure, In Vernier you will get different reading for different pressure of your thumb. The difference will not be much but if you talk about accuracy it will affect.

- **WHAT IS FRL**

FRL unit is a Pneumatic device , which contains Filter, Regulator and Lubricator in a single unit.

**MAIN TYPE OF MEASURING INSTRUMENTS**



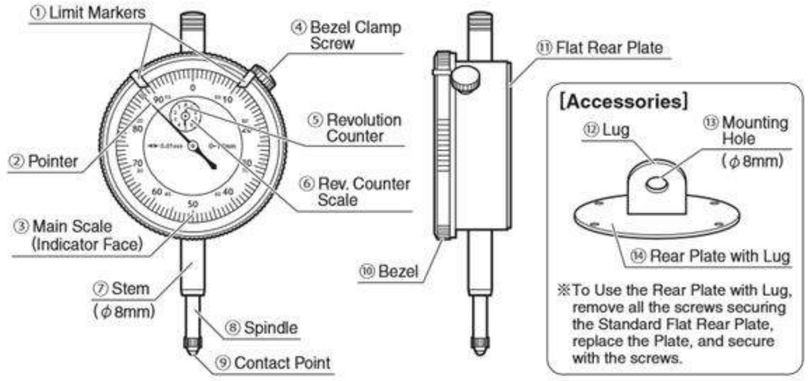
| Applied for | Measurement Instrument |
|---|---|
| Length | •Steel scale, Calipers •Dividers •Micrometer •Vernier calipers<br>•Thickness gauge •Elevation gauge •Planer gauge •Side length gauge<br>•Dial gauge •Minimeter •Pasa meter<br>•Feeler gauge •Standard gauge •Limit gauge<br>•Optical meter •Electrical micrometer •Air micrometer<br>•Tool microscope •Cylinder gauge •Depth gauge, etc. |
| Angle | •Angle gauge •Square •Protractor •Combination square<br>•Sine bar •Taper gauge •Protractor with level •Dividing plate, etc. |
| Planeness | •Level •Straight edge •Scribing block •Surface plate •Beam surface plate •<br>Roughness meter, etc. |

- **WHAT IS OSHA & ISO –STANDARDS?**
  - **OSHA** -Occupational Safety and Health Administration
  - **ISO** - International Organization for Standardization
  - **ISO 9000** - quality management systems
  - **ISO 9001** - quality assurance in design, development, production, installation, and servicing
  - **ISO 9002** - quality assurance in production, installation, and servicing
  - **ISO 9003** - quality assurance in final inspection and test covered only the final inspection of finished product
  - **ISO 10006** -Quality management—Guidelines to quality management in projects
  - **ISO 14001** -Environmental management standards
  - **OSHA 18000**-An international occupational health and safety management system specification

## How to Read a Dial Indicator

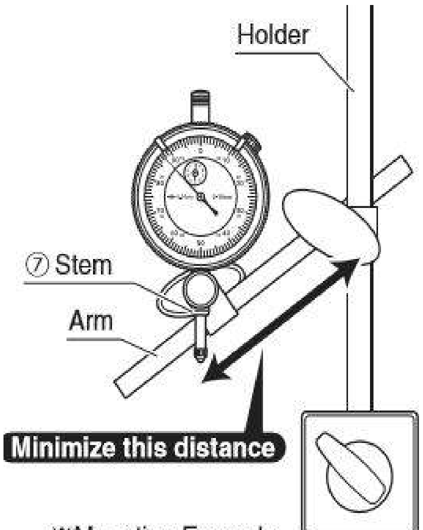
Dial indicators are measuring devices designed expressly to measure relative position. The primary parts of a dial indicator are the face or dial, the case, and the plunger. The plunger is a spring loaded part that can be depressed into the case causing the dial to move clockwise. Uses for Parallelism, Flatness, Run out …etc…

- Measuring machine tools positioning accuracy
- measuring run out for rotary shafts
- Checking vise parallelism on milling machines
- Measuring flatness of surfaces and assemblies
- Confirming machine tool feed distance



① Limit Markers
④ Bezel Clamp Screw
⑪ Flat Rear Plate
② Pointer
⑤ Revolution Counter
⑥ Rev. Counter Scale
③ Main Scale (Indicator Face)
⑦ Stem (ϕ8mm)
⑩ Bezel
⑧ Spindle
⑨ Contact Point
[Accessories]
⑫ Lug
⑬ Mounting Hole (ϕ8mm)
⑭ Rear Plate with Lug
※To Use the Rear Plate with Lug, remove all the screws securing the Standard Flat Rear Plate, replace the Plate, and secure with the screws.

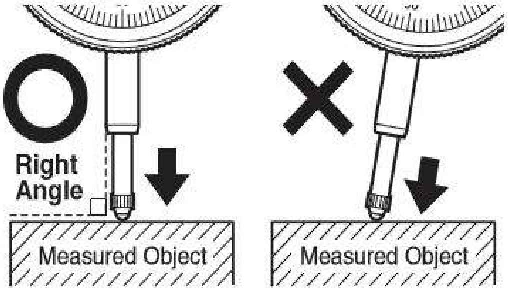
| | |
|---|---|
| ①Limit Markers | For marking acceptance range for Pass/Fail testing |
| ②Pointer | Main Scale indicator |
| ③Main Scale (Indicator Face) | Main Scale, rotate Bezel (⑩) to turn |
| ④Bezel Clamp Screw | Clamps Scale to prevent rotation |
| ⑤Revolution Counter | Pointer indicates Main Scale x100 |
| ⑥Rev. Counter Scale | Each division is Main Scale x100 |
| ⑦Stem | For holding and mounting Gauge (ϕ8mm) |
| ⑧Spindle | Shaft moves up and down with measurement |
| ⑨Contact Point | Replaceable tip in contact with workpiece |
| ⑩Bezel | Rotate to turn Main Scale (③) |
| ⑪Flat Rear Plate | Standard back cover |
| ⑫Lug | For mounting Gauge |
| ⑬Mounting Hole | ϕ8mm, for mounting Gauge |
| ⑭Rear Plate with Lug | Accessory back cover for mounting Gauge using Lug |



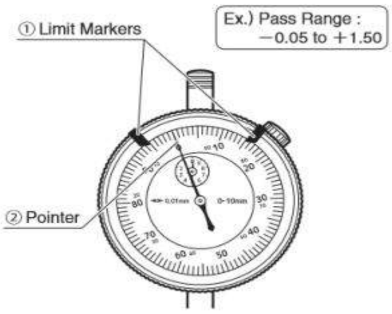
Holder
⑦ Stem
Arm
Minimize this distance

※Mounting Example

Confirm that the Contact Point and Rear Cover are tightly fastened. If loose, please re-tighten the Rear Plate Screws. Attach to the Holder using the Stem or Rear Lug. Mounting Gauge by other than Stem or Lug will cause inaccuracy and product damage. Confirm that Pointer and Revolution Counter movement is smooth. Using fingertip, gently press on Contact Point to move the Spindle up and down. Motion of Pointers should be smooth. If it is not smooth make sure Stem is not clamped to Holder too tight, and adjust. Also make sure Pointer is stable at set position. Make sure Spindle axis is perpendicular to measured surface. If Spindle (Contact Point) is not at a right angle to surface, Gauge will not operate properly and measurement will be inaccurate. Always keep the Spindle axis perpendicular. When used to check parallelism of Milling Machine vise, use a Magnetic Base to mount the Gauge perpendicular to surface, and move it out of the way during operation to prevent interference.



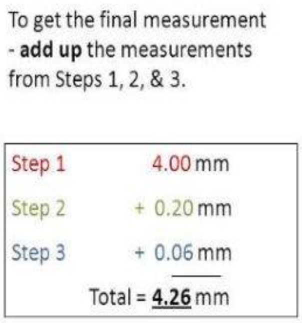
Right Angle
Measured Object
Measured Object



① Limit Markers
Ex.) Pass Range : −0.05 to +1.50
② Pointer

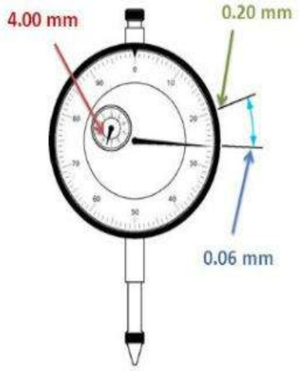
**HOW TO USE** - Comparison Measurements ①Set Up Reference Part. Carefully lift Spindle with fingertip, and, taking care not to hit Spindle from the side, insert the Reference Part or Master under Contact Point. ② Set the Origin. Adjust the gauge mount or rotate the Bezel to set the Gauge to "0". ③Remove Reference, and begin measurements. Remove Reference or Master, careful not to shock Spindle. Insert part to be measured and read the measurement off the Scale. Setting the Limit Markers Limit Markers can be moved to show acceptance range for measurements.

**Reading the dial indicator:**

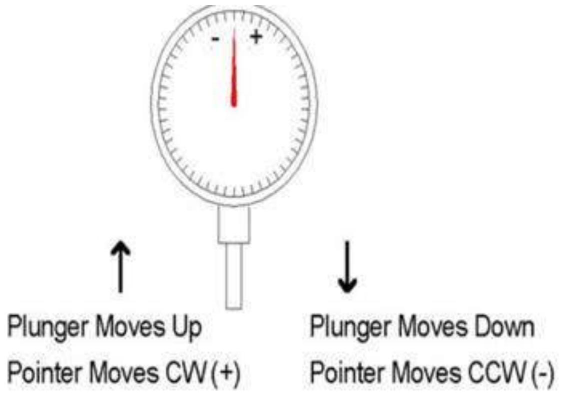


To get the final measurement - **add up** the measurements from Steps 1, 2, & 3.

| | |
|---|---|
| Step 1 | 4.00 mm |
| Step 2 | + 0.20 mm |
| Step 3 | + 0.06 mm |
| | Total = **4.26** mm |



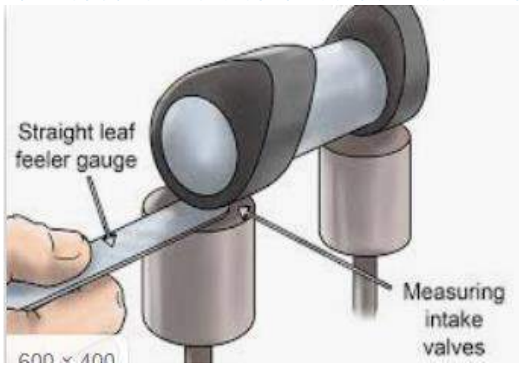
4.00 mm
0.20 mm
0.06 mm



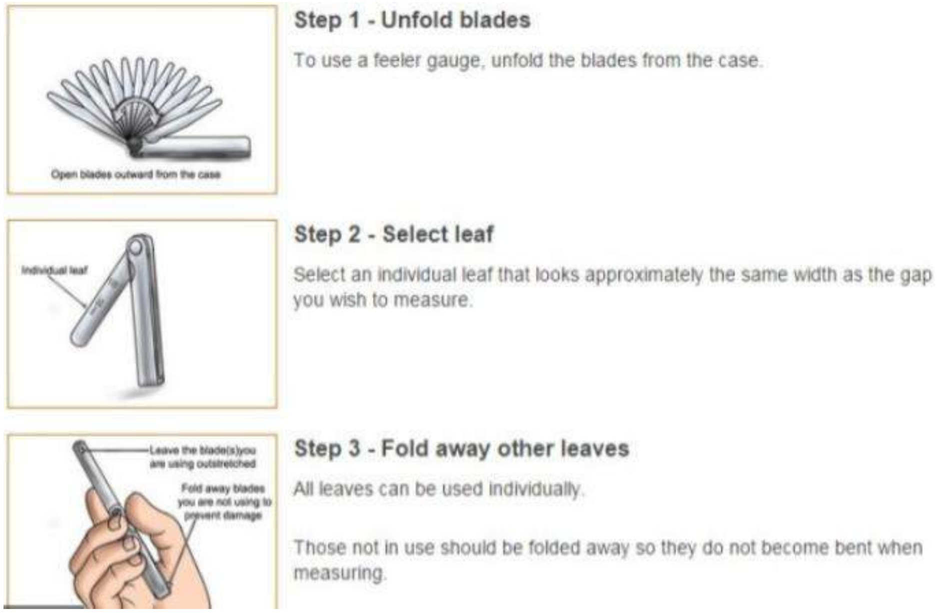
-
+
Plunger Moves Up
Pointer Moves CW (+)
Plunger Moves Down
Pointer Moves CCW (-)

- **What is feeler gauge & use:**

A **feeler gauge** is a tool used to measure gap widths. **Feeler gauges** are mostly used in engineering to measure the clearance between two parts.


Straight leaf feeler gauge
Measuring intake valves
600 x 400

**How to use feeler gauge**:


Open blades outward from the case
Individual leaf
Leave the blade(s)you are using outstretched
Fold away blades you are not using to prevent damage

**Step 1 - Unfold blades**

To use a feeler gauge, unfold the blades from the case.

**Step 2 - Select leaf**

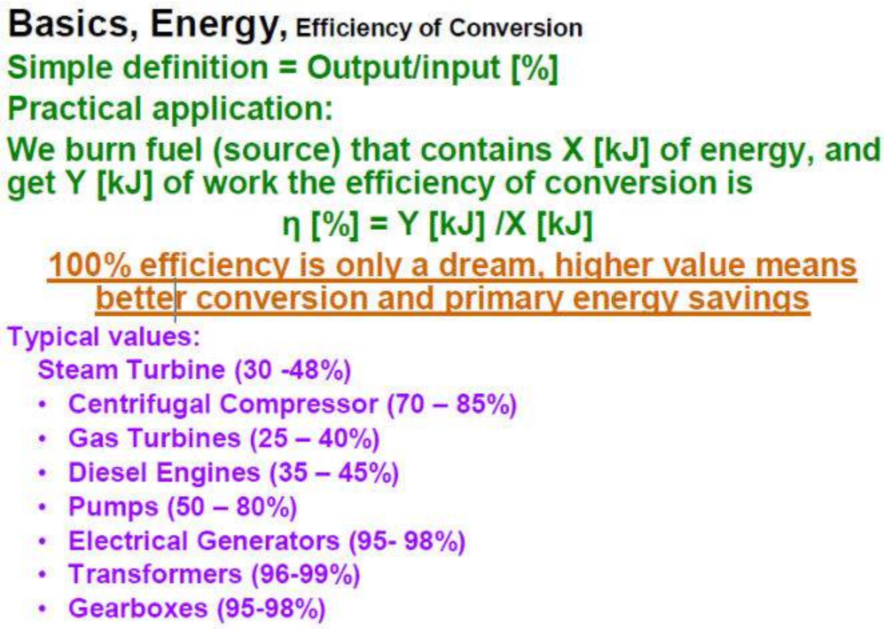
Select an individual leaf that looks approximately the same width as the gap you wish to measure.

**Step 3 - Fold away other leaves**

All leaves can be used individually.

Those not in use should be folded away so they do not become bent when measuring.

- **Normal Efficiency of equipments :**



**Basics, Energy, Efficiency of Conversion**

Simple definition = Output/input [%]

Practical application:

We burn fuel (source) that contains X [kJ] of energy, and get Y [kJ] of work the efficiency of conversion is

$$\eta\ [\%] = Y\ [kJ] / X\ [kJ]$$

100% efficiency is only a dream, higher value means better conversion and primary energy savings

Typical values:

Steam Turbine (30 -48%)
- Centrifugal Compressor (70 – 85%)
- Gas Turbines (25 – 40%)
- Diesel Engines (35 – 45%)
- Pumps (50 – 80%)
- Electrical Generators (95- 98%)
- Transformers (96-99%)
- Gearboxes (95-98%)

**Preparation for new plant start up :**

- ✓ Collect equipments IOM , drawing , P & ID ,ISO drawing form EPC / PMT team
- ✓ prepare SPIR (spare part list with cross section drawing ) , make min/max for equipments & daily consumables
- ✓ Make list of lubricants (oil & grease), required qty
- ✓ prepare equipment inspection , PM & OH check list as well procedure
- ✓ prepare list of tools & tackles
- ✓ prepare list of PSV/TSV , measuring tools for calibration
- ✓ pre commissioning / commissioning documents
- ✓ diferent type of valves list for future referance / spares
- ✓ list of special tools
- ✓ list of mechanical seals & bearings
- ✓ prepare xl sheet for rotary & static equipments for ready referance ( complete details)

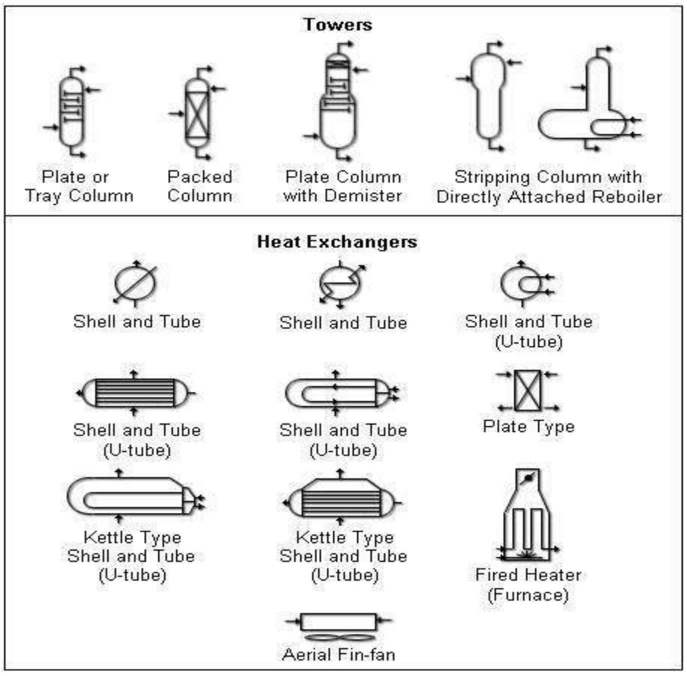
## API & SAP code:

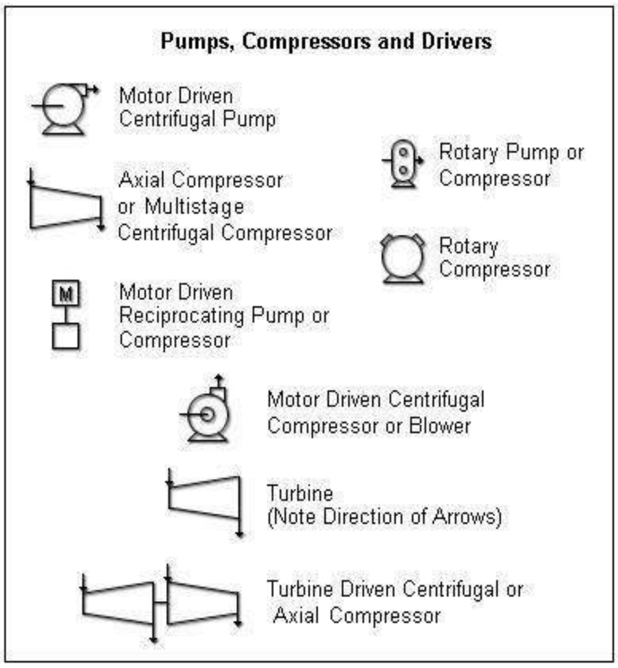
- ✓ **Note:** Always refer API code/standard.

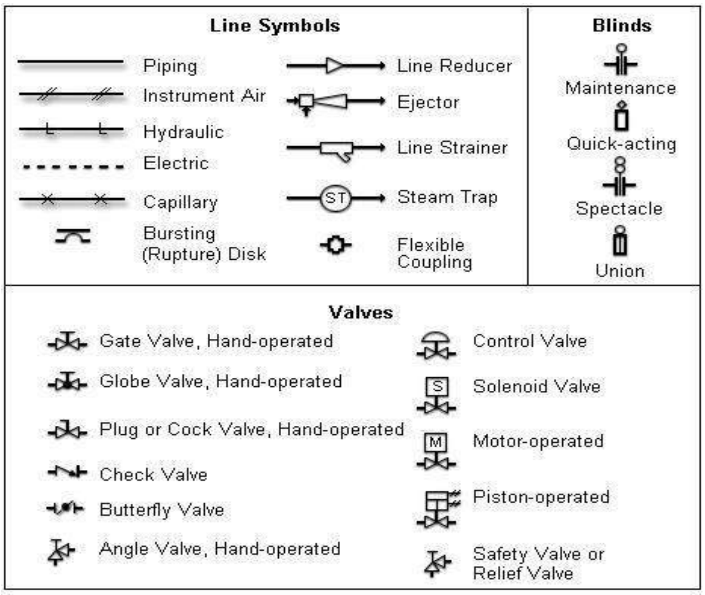
| API CODE | |
|---|---|
| 570 | Piping Inspection |
| 620 | Storage tank inspection |
| 572 / 510 | Pressure vessel inspection |
| 520 ,526 ,527 , 576 | Safety valve - PSV , TSV |
| 574 | Piping fitting inspection |
| 650, 653 | Atmospheric tank inspection |
| 660 | Heat exchanger inspection |
| 610 | Centrifugal pump inspection |
| 686 | Rotating m/c installation / alignment |
| 670 | Rotating m/c preservation / protection |
| 577 | Welding inspection |
| 619 | Rotary screw compressor inspection |
| 598 | Valve inspection & testing |
| 611, 612 | Steam turbine |
| 616 | gas turbine |
| BS (British / European STD) 1139 & 12811 | Scaffolding standard |
| 530, 560, 573 | Boiler / Furnace maintenance |
| 617 , 672 | Centrifugal compressor |
| 618 | Reciprocating compressor |
| 674 | Reciprocating pump |
| 676 | Rotary positive displacement pump (PD pump) |
| 610, 682 | Mechanical seal |
| **SAP TRANSITION CODE (for daily maintenance / purchase)** | |
| IW 21 | Create notification |
| IW 22 | Change notification |
| IW 23 & IW29 | Display Notifications /PM notification |
| IW 28 | Create W O |
| IW31 | Create Work Order, create PM order |
| IW32 & IW38 | Change Notifications, change PM order |
| IW33 & IW39 | Display PM & Work Order |
| IW 41 /43 | Confirm WO |
| ME 23 | Display PO (Purchase order) |
| ME 51N | Crete PR (purchase requisition) |
| ME 52N | Change PR |
| ME 53N | PR display |
| MMBE /MM03 / MD04 | Material stock overview |
| MB 21 / 24 | Create material reservation |
| IL03 | Display Functional Location of material |
| IE03 & IH08 | Display Equipment |
| IB03 | Display BOM |

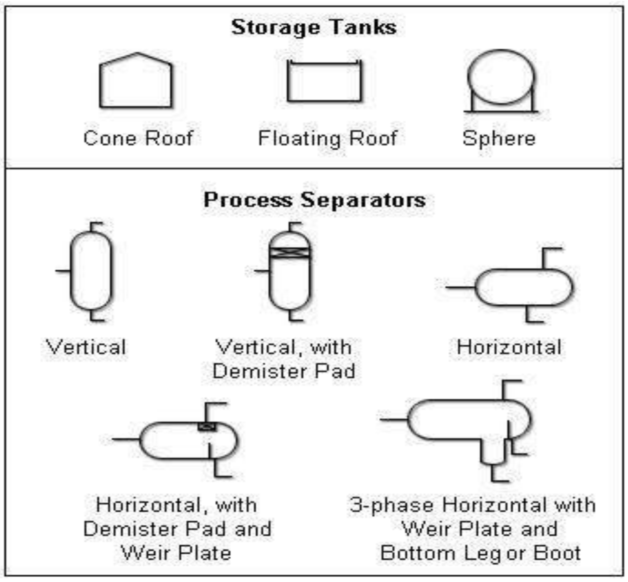
- ✓ **ERP** - Enterprise resource planning
- ✓ **SCADA** - Supervisory control and data acquisition
- ✓ **SAP** – systematic application procedure
- ✓ **CMMS** -Computerized maintenance management system

## P & ID –SYMBOLS


Towers
Plate or Tray Column
Packed Column
Plate Column with Demister
Stripping Column with Directly Attached Reboiler
Heat Exchangers
Shell and Tube
Shell and Tube
Shell and Tube (U-tube)
Shell and Tube (U-tube)
Shell and Tube (U-tube)
Plate Type
Kettle Type Shell and Tube (U-tube)
Kettle Type Shell and Tube (U-tube)
Fired Heater (Furnace)
Aerial Fin-fan

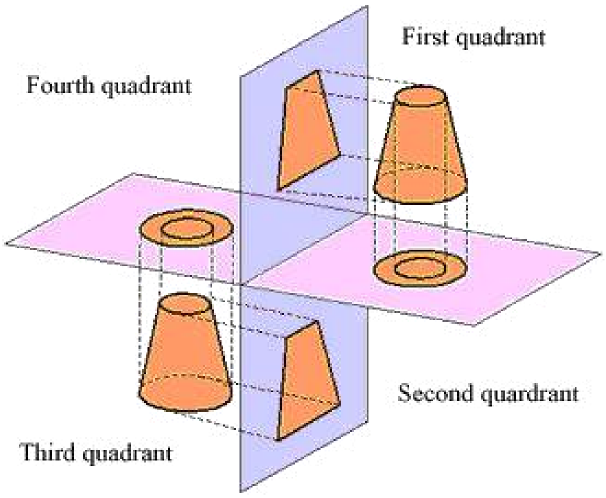

Pumps, Compressors and Drivers
Motor Driven Centrifugal Pump
Rotary Pump or Compressor
Axial Compressor or Multistage Centrifugal Compressor
Rotary Compressor
Motor Driven Reciprocating Pump or Compressor
M
Motor Driven Centrifugal Compressor or Blower
Turbine (Note Direction of Arrows)
Turbine Driven Centrifugal or Axial Compressor

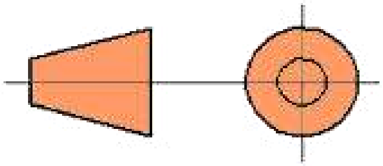

Line Symbols
Piping
Instrument Air
Hydraulic
Electric
Capillary
Bursting (Rupture) Disk
Line Reducer
Ejector
Line Strainer
ST
Steam Trap
Flexible Coupling
Blinds
Maintenance
Quick-acting
Spectacle
Union
Valves
Gate Valve, Hand-operated
Globe Valve, Hand-operated
Plug or Cock Valve, Hand-operated
Check Valve
Butterfly Valve
Angle Valve, Hand-operated
Control Valve
S
Solenoid Valve
M
Motor-operated
Piston-operated
Safety Valve or Relief Valve

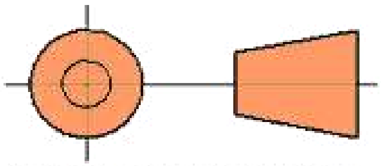

Storage Tanks
Cone Roof
Floating Roof
Sphere
Process Separators
Vertical
Vertical, with Demister Pad
Horizontal
Horizontal, with Demister Pad and Weir Plate
3-phase Horizontal with Weir Plate and Bottom Leg or Boot

### Orthographic projections : First and third angle projection

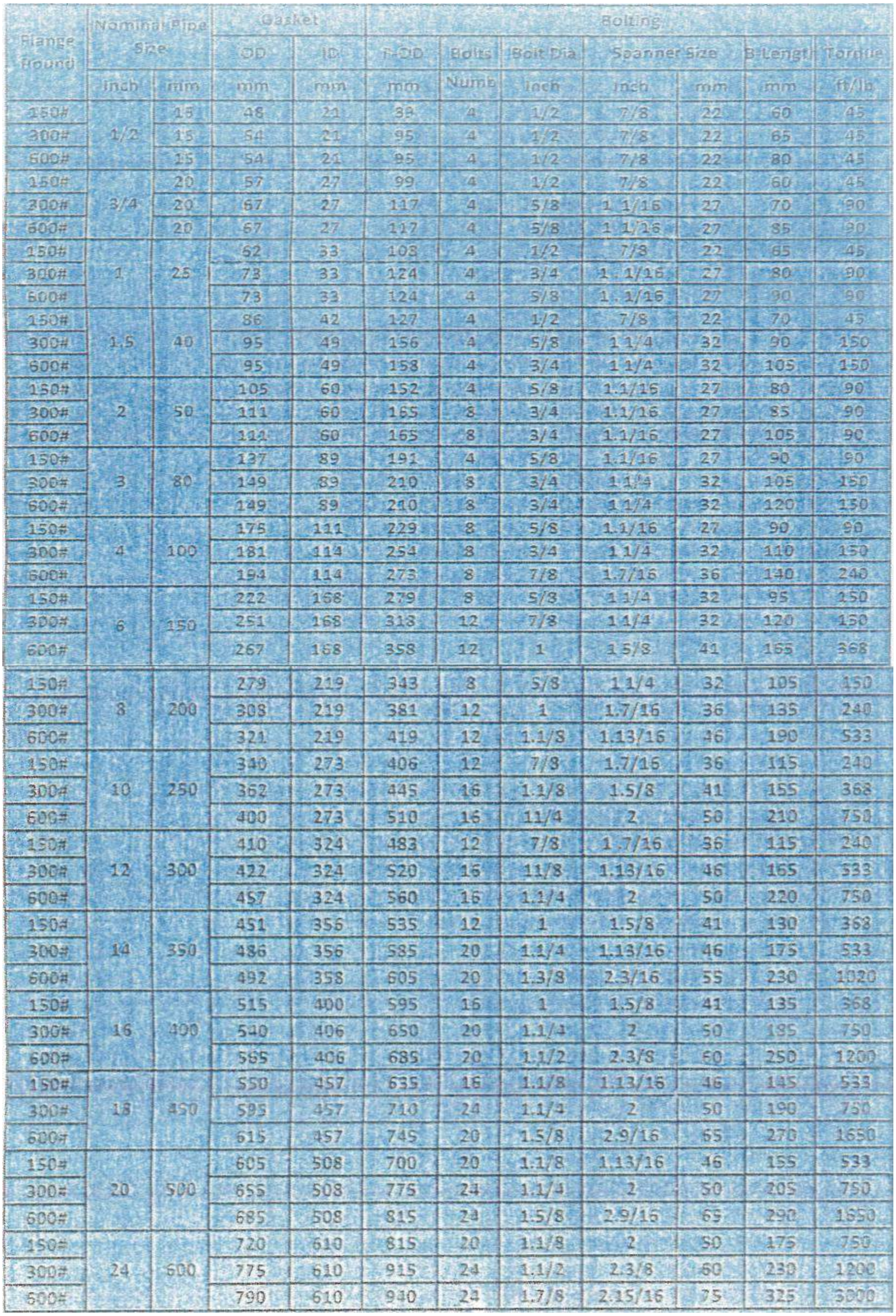
This is a graphical method used in engineering drawings. The word **orthographic** is derived from the Greek words **orthos**-straight, rectangular and **graphos**-written, drawn. A drawing drawn using the following **projection methods**: (a) orthogonal (b) oblique and/or (c) perspective ,
**Two methods of orthographic projections use**:1) first angle projection and 2) third angle projection , Both systems of projection are approved internationally and the system used is clearly indicated on all engineering drawings with the following illustrations:


First quadrant
Fourth quadrant
Second quardrant
Third quadrant


First angle projection


Third angle projection

## GASKET, BOLT, TORQUE & SPANNER SIZE:



| Flange Pound | Nominal Pipe Size | | Gasket | | Bolting | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | OD | ID | P.C.D | Bolts | Bolt Dia | Spanner Size | | B-Lengt | Torque |
| | Inch | mm | mm | mm | mm | Numb | Inch | Inch | mm | mm | ft/lb |
| 150# | 1/2 | 15 | 48 | 21 | 38 | 4 | 1/2 | 7/8 | 22 | 60 | 45 |
| 300# | | 15 | 54 | 21 | 95 | 4 | 1/2 | 7/8 | 22 | 65 | 45 |
| 600# | | 15 | 54 | 21 | 95 | 4 | 1/2 | 7/8 | 22 | 80 | 45 |
| 150# | 3/4 | 20 | 57 | 27 | 99 | 4 | 1/2 | 7/8 | 22 | 60 | 45 |
| 300# | | 20 | 67 | 27 | 117 | 4 | 5/8 | 1 1/16 | 27 | 70 | 90 |
| 600# | | 20 | 67 | 27 | 117 | 4 | 5/8 | 1 1/16 | 27 | 85 | 90 |
| 150# | 1 | 25 | 62 | 33 | 108 | 4 | 1/2 | 7/8 | 22 | 65 | 45 |
| 300# | | | 73 | 33 | 124 | 4 | 3/4 | 1. 1/16 | 27 | 80 | 90 |
| 600# | | | 73 | 33 | 124 | 4 | 5/8 | 1. 1/16 | 27 | 90 | 90 |
| 150# | 1.5 | 40 | 86 | 42 | 127 | 4 | 1/2 | 7/8 | 22 | 70 | 45 |
| 300# | | | 95 | 49 | 156 | 4 | 5/8 | 1 1/4 | 32 | 90 | 150 |
| 600# | | | 95 | 49 | 158 | 4 | 3/4 | 1 1/4 | 32 | 105 | 150 |
| 150# | 2 | 50 | 105 | 60 | 152 | 4 | 5/8 | 1.1/16 | 27 | 80 | 90 |
| 300# | | | 111 | 60 | 165 | 8 | 3/4 | 1.1/16 | 27 | 85 | 90 |
| 600# | | | 111 | 60 | 165 | 8 | 3/4 | 1.1/16 | 27 | 105 | 90 |
| 150# | 3 | 80 | 137 | 89 | 191 | 4 | 5/8 | 1.1/16 | 27 | 90 | 90 |
| 300# | | | 149 | 89 | 210 | 8 | 3/4 | 1 1/4 | 32 | 105 | 150 |
| 600# | | | 149 | 89 | 210 | 8 | 3/4 | 1 1/4 | 32 | 120 | 150 |
| 150# | 4 | 100 | 175 | 111 | 229 | 8 | 5/8 | 1.1/16 | 27 | 90 | 90 |
| 300# | | | 181 | 114 | 254 | 8 | 3/4 | 1 1/4 | 32 | 110 | 150 |
| 600# | | | 194 | 114 | 273 | 8 | 7/8 | 1.7/16 | 36 | 140 | 240 |
| 150# | 6 | 150 | 222 | 168 | 279 | 8 | 5/8 | 1 1/4 | 32 | 95 | 150 |
| 300# | | | 251 | 168 | 318 | 12 | 7/8 | 1 1/4 | 32 | 120 | 150 |
| 600# | | | 267 | 168 | 358 | 12 | 1 | 1 5/8 | 41 | 165 | 368 |
| 150# | 8 | 200 | 279 | 219 | 343 | 8 | 5/8 | 1 1/4 | 32 | 105 | 150 |
| 300# | | | 308 | 219 | 381 | 12 | 1 | 1.7/16 | 36 | 135 | 240 |
| 600# | | | 321 | 219 | 419 | 12 | 1.1/8 | 1.13/16 | 46 | 190 | 533 |
| 150# | 10 | 250 | 340 | 273 | 406 | 12 | 7/8 | 1.7/16 | 36 | 115 | 240 |
| 300# | | | 362 | 273 | 445 | 16 | 1.1/8 | 1.5/8 | 41 | 155 | 368 |
| 600# | | | 400 | 273 | 510 | 16 | 11/4 | 2 | 50 | 210 | 750 |
| 150# | 12 | 300 | 410 | 324 | 483 | 12 | 7/8 | 1 .7/16 | 36 | 115 | 240 |
| 300# | | | 422 | 324 | 520 | 16 | 11/8 | 1.13/16 | 46 | 165 | 533 |
| 600# | | | 457 | 324 | 560 | 16 | 1.1/4 | 2 | 50 | 220 | 750 |
| 150# | 14 | 350 | 451 | 356 | 535 | 12 | 1 | 1.5/8 | 41 | 130 | 368 |
| 300# | | | 486 | 356 | 585 | 20 | 1.1/4 | 1.13/16 | 46 | 175 | 533 |
| 600# | | | 492 | 358 | 605 | 20 | 1.3/8 | 2.3/16 | 55 | 230 | 1020 |
| 150# | 16 | 400 | 515 | 400 | 595 | 16 | 1 | 1.5/8 | 41 | 135 | 368 |
| 300# | | | 540 | 406 | 650 | 20 | 1.1/4 | 2 | 50 | 185 | 750 |
| 600# | | | 565 | 406 | 685 | 20 | 1.1/2 | 2.3/8 | 60 | 250 | 1200 |
| 150# | 18 | 450 | 550 | 457 | 635 | 16 | 1.1/8 | 1.13/16 | 46 | 145 | 533 |
| 300# | | | 595 | 457 | 710 | 24 | 1.1/4 | 2 | 50 | 190 | 750 |
| 600# | | | 615 | 457 | 745 | 20 | 1.5/8 | 2.9/16 | 65 | 270 | 1650 |
| 150# | 20 | 500 | 605 | 508 | 700 | 20 | 1.1/8 | 1.13/16 | 46 | 155 | 533 |
| 300# | | | 655 | 508 | 775 | 24 | 1.1/4 | 2 | 50 | 205 | 750 |
| 600# | | | 685 | 508 | 815 | 24 | 1.5/8 | 2.9/16 | 65 | 290 | 1650 |
| 150# | 24 | 600 | 720 | 610 | 815 | 20 | 1.1/8 | 2 | 50 | 175 | 750 |
| 300# | | | 775 | 610 | 915 | 24 | 1.1/2 | 2.3/8 | 60 | 230 | 1200 |
| 600# | | | 790 | 610 | 940 | 24 | 1.7/8 | 2.15/16 | 75 | 325 | 3000 |

Torque is a measure of force , One foot-pound (ft/lb-one pound acting on a lever one foot away from an axle will be one lb-ft of torque) is equal to 1.356 newton-meters (Nm-One newton-meter is equal to the torque resulting from a force of one newton applied perpendicularly to the end of a moment arm that is one meter long.).

## Material normally used in industries:

1) **Mild steel (M S )** : A soft general purpose metal used for making pins , rivets , handles , mandrills , metal packing , clamp..etc ..
2) **Carbon steel ( C S )** : general purpose material that can be hardened and used for making threaded plug , nuts , bolts , washers , ordinary shaft etc..
3) **Cast iron ( C I )** : hard porous and free cutting material , used for lapping blocks , wear rings , intermediate bushing , piston ring etc . very good lubricant property because of presence of free graphite . better capacity to absorb shocks and vibrations.
4) **EN 24** : carbon alloy steel that can be hardened , used for shaft , dowels and other jobs where strength is important .
5) **SS 316** : Non magnetic stainless steel . resistant to heat and corrosion . used for shaft sleeve , seat , valve spindle .
6) **SS 410** : Magnetic stainless steel that can be hardened . water resistant . used for wear rings , snap rings.
7) **SS 304** : non magnetic stainless steel with high temperature strength and corrosion resistance . used for making shaft sleeve , valve spindles..
8) **Monel** : an alloy of copper and nickel ( proportion 70:30 respectively ) , slightly magnetic in nature . highly resistant to acid corrosion . used for spare parts of equipment used in acid services such as shaft sleeve , retainers…
9) **Hastealloy B** : alloy of nickel and molybdenum ( proportion 60:30 respectively) very hard and difficult to machine . used for making spare parts for equipment in extremely corrosive services where normal stainless steel cannot with stand .
10) **Hastealloy C** : same as Hastealloy B but slightly softer .
11) **Phosphor Bronze** : An alloy of copper and tin . used for parts in salty water . also use to make bushes , bush bearings , wear rings , worm wheels etc..
12) **White metal alloy** : alloy of copper , antimony and tin ( percentage -3.5 , 7 and 89.5 respectively ) used for friction bearings because of their superior load carrying capacity , ability to embed of acids and not prone to oil film failure , however major drawback is that they have low fatigue resistance .
13) **Stellite** : non ferrous alloy consisting of cobalt , tungsten and chromium . it has good shock resistance and retains hardness in elevated temperatures as high as 800 – 900 c.
14) **Ceramics** :its cemented oxide and constitute of aluminum oxide ( AL2O3-99.5 %).It's cheaper than any other sintered oxide . it can withstand elevated temp. up to 1200 c without losing hardness . its more brittle but at same time more wear resistant than sintered carbide . ceramic is a super fine grain high alumina ceramic material that exhibits excellent low wear characteristics . it's the best seal face material for highly corrosive material.
15) **Silicon Carbide** : highly resistant to thermal stress and corrosion in high temperature oxidizing atmospheres . exhibits low wear properties . Its twice as hard as tungsten carbide and also exhibit better dry run capabilities.
16) **Carbon M** : metal impregnated (antimony) hard carbon that is especially suited for extremely heavy duty application involving non corrosive media. Have better abrasive resistance and show emergency dry run characteristic.
17) **Carbon R** : resin impregnated hard carbon recommended for general purpose application involving corrosive fluids . Exhibit good resistance to thermal shocks and good dimensional stability over a wide range of temperature . In addition to that they have low permeability and good thermal conductivity.
18) **Aluminum** : soft material that can be machined with coolant , used for gasket .
19) **Aluminum bronze** : high alloy of copper and aluminum , used in casting , rollers and where there is water corrosion . Not to be used as bearing material.

### Elastomer / rubber Seal materials

20) **Neoprene** : A multipurpose synthetic rubber which is resistance to chemicals , oils , greases etc . Used for making oil seals , o rings and gaskets etc..
21) **Buna N** : highly acrylonitrile copolymer rubber specially compounded for ball seals . At moderate temperature , it resists abrasion , oil and solvents . Very good material for o ring and gasket .
22) **Viton** : heat resistant material to abrasion , grease etc . Useful in oil , fuels and solvent services . It persists permanent seat .
23) **Silicon rubber** : this rubber when compounded with filler and vulcanizing agents products having rubber products having good physical properties over a wide range of temperature . useful for steam services within the specified range , used for o ring , gaskets.
    Drawback: tendency to swell caused by abrasion of water & natural affinity to the metal surface

24) **Teflon (PTFE-** Polytetrafluoroethylene **)** : it's tough and rigid TETRAFLUOROETHYLENE RESIN having temperature , chemical and antifriction properties . It is widely used for seals and steam packing , contained gasket and wedges in mechanical seals . It is inert to chemical attack. It is affected only by substances like alkaline metals and fluorine. Its wax like surface offers lowest co efficient of friction .

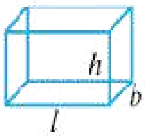
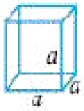
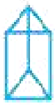
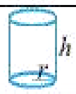
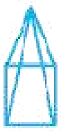
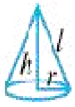
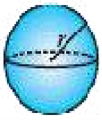
25) **Kel – F:** its polymer of trifluorochloroethylene and non flammable , stable and colorless . it is chemically inert and resistant to temperature ( thermoplastic) . It has high compreesive strength , resistant to thermal shocks and does not absorb moisture . The ball seal of this material can be used for temp. as low as minus 350 c

26) **Nylon :** it is poly amide resin . It is strong and has resistance to abrasion and chemicals . Nylon absorbs water and should not be used in contact with water or moisture . It is suitable for hydraulic system , lubricants-gases and high pressure system.

27) **Derlin** : it is thermoplastic acetyl resin that is tough , resilient and retains dimensional stability and physical properties over a wide range of service condition such as temp, humidity,exposure to solvent /chemical etc . It is the strongest thermoplastic and resistance to heat and abrasion . It is ideal for high pressure ball seals but not for steam packing , body seal or gaskets .

28) **Polyethylene :** it is thermoplastic polymer of ethylene . Three types of polyethylene – LDPE,MDPE,HDPE . It has remarkable physical properties over wide range of service condition and is used widely in industries.

## Area, volume --formulas

| Name of the Solid | Figure | Lateral/Curved Surface Area | Total Surface Area | Volume | Nomenclature |
|---|---|---|---|---|---|
| Cuboid |  | $2h(l+b)$ | $2(lb+bh+hl)$ | $lbh$ | $l$ : length<br>$b$ : breadth<br>$h$ : height |
| Cube |  | $4a^2$ | $6a^2$ | $a^3$ | $a$: side of the cube |
| Right prism |  | Perimeter of base × height | Lateral surface area + 2 (area of one end) | Area of base × height | – |
| Right circular cylinder |  | $2\pi rh$ | $2\pi r(r+h)$ | $\pi r^2 h$ | $r$ : radius of the base<br>$h$ : height |
| Right pyramid |  | $\frac{1}{2}$(perimeter of base) × slant height | Lateral surface area + area of the base | $\frac{1}{3}$(area of the base) ×height | – |
| Right circular cone |  | $\pi rl$ | $\pi r(l+r)$ | $\frac{1}{3}\pi r^2 h$ | $r$ : radius of the base<br>$h$ : height<br>$l$ : slant height |
| Sphere (Solid) |  | $4\pi r^2$ | $4\pi r^2$ | $\frac{4}{3}\pi r^3$ | $r$ : radius |
| Hemisphere (Solid) | | $2\pi r^2$ | $3\pi r^2$ | $\frac{2}{3}\pi r^3$ | $r$ : radius |

## Piping schedule: Up to 10 "----STD. and 40 schedule wall thicknesses are same.

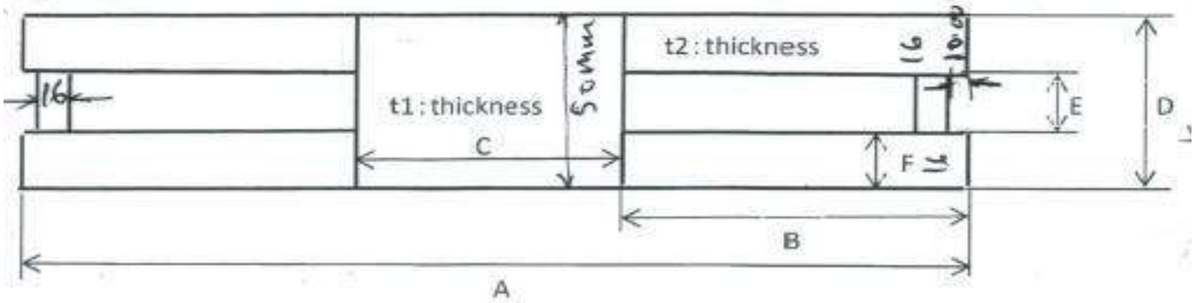
| Nominal Pipe Size (Inches) | O/d (mm) | Standard | | Extra Strong | | Schedule 10 | | Schedule 20 | | Schedule 30 | | Schedule 40 | | Schedule 60 | | Schedule 80 | | Schedule 100 | | Schedule 120 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Wall | Kg/m | Wall | Kg/m | Wall | Kg/m | Wall | Kg/m | Wall | Kg/m | Wall | Kg/m | Wall | Kg/m | Wall | Kg/m | Wall | Kg/m | Wall | Kg/m |
| 1/2 | 21.3 | 2.77 | 1.27 | 3.73 | 1.62 | | | | | | | 2.77 | 1.27 | | | 3.73 | 1.62 | | | | |
| 3/4 | 26.7 | 2.87 | 1.69 | 3.91 | 2.20 | | | | | | | 2.87 | 1.69 | | | 3.91 | 2.20 | | | | |
| 1 | 33.4 | 3.38 | 2.50 | 4.55 | 3.24 | 2.77 | 2.12 | | | | | 3.38 | 2.50 | | | 4.55 | 3.24 | | | | |
| 1 1/4 | 42.2 | 3.56 | 3.39 | 4.85 | 4.47 | | | | | | | 3.56 | 3.39 | | | 4.85 | 4.47 | | | | |
| 1 1/2 | 48.3 | 3.68 | 4.05 | 5.08 | 5.41 | | | | | | | 3.68 | 4.05 | | | 5.08 | 5.41 | | | | |
| 2 | 60.3 | 3.91 | 5.44 | 5.54 | 7.48 | 2.77 | 3.99 | | | | | 3.91 | 5.44 | | | 5.54 | 7.48 | | | | |
| 2 1/2 | 73 | 5.16 | 8.63 | 7.01 | 11.41 | 3.05 | 5.34 | | | | | 5.16 | 8.63 | | | 7.01 | 11.41 | | | | |
| 3 | 88.9 | 5.49 | 11.29 | 7.62 | 15.27 | 3.05 | 6.56 | | | | | 5.49 | 11.29 | | | 7.62 | 15.27 | | | | |
| 3 1/2 | 101.6 | 5.74 | 13.57 | 8.08 | 18.63 | 3.05 | 7.43 | | | | | 5.74 | 13.57 | | | 8.08 | 18.63 | | | | |
| 4 | 114.3 | 6.02 | 16.07 | 8.56 | 22.32 | 3.05 | 8.50 | | | | | 6.02 | 16.07 | | | 8.56 | 22.32 | | | 11.13 | 28.32 |
| 5 | 141.3 | 6.55 | 21.77 | 9.53 | 30.97 | 3.40 | 11.74 | | | | | 6.55 | 21.77 | | | 9.53 | 30.97 | | | 12.70 | 40.28 |
| 6 | 168.3 | 7.11 | 28.26 | 10.97 | 42.56 | 3.40 | 14.04 | | | | | 7.11 | 28.26 | | | 10.97 | 42.56 | | | 14.27 | 54.20 |
| 8 | 219.1 | 8.18 | 42.55 | 12.70 | 64.64 | 3.76 | 20.27 | 6.35 | 33.31 | 7.04 | 36.81 | 8.18 | 42.55 | 10.31 | 53.08 | 12.70 | 64.64 | 15.09 | 75.92 | 18.26 | 90.44 |
| 10 | 273.1 | 9.27 | 60.31 | 12.70 | 81.55 | 4.19 | 28.21 | 6.35 | 41.77 | 7.80 | 51.03 | 9.27 | 60.31 | 12.70 | 81.55 | 15.09 | 96.01 | 18.26 | 114.75 | 21.44 | 133.06 |
| 12 | 323.9 | 9.53 | 73.88 | 12.70 | 97.46 | 4.57 | 36.54 | 6.35 | 49.73 | 8.38 | 65.20 | 10.31 | 79.73 | 14.27 | 108.96 | 17.48 | 132.08 | 21.44 | 159.91 | 25.40 | 186.97 |
| 14 | 355.6 | 9.53 | 81.33 | 12.70 | 107.39 | 6.35 | 54.69 | 7.92 | 67.90 | 9.53 | 81.33 | 11.13 | 94.55 | 15.09 | 126.71 | 19.05 | 158.10 | 23.83 | 194.96 | 27.79 | 224.65 |
| 16 | 406.4 | 9.53 | 93.27 | 12.70 | 123.30 | 6.35 | 62.64 | 7.92 | 77.83 | 9.53 | 93.27 | 12.70 | 123.30 | 16.66 | 160.12 | 21.44 | 203.53 | 26.19 | 245.56 | 30.95 | 286.64 |
| 18 | 457 | 9.53 | 105.16 | 12.70 | 139.15 | 6.35 | 70.57 | 7.92 | 87.71 | 11.13 | 122.38 | 14.27 | 155.80 | 19.05 | 205.74 | 23.83 | 254.55 | 29.36 | 309.62 | 34.93 | 363.56 |
| 20 | 508 | 9.53 | 117.50 | 12.70 | 155.12 | 6.35 | 78.55 | 9.53 | 117.15 | 12.70 | 156.12 | 15.09 | 183.42 | 20.62 | 247.83 | 26.19 | 311.17 | 32.54 | 381.53 | 38.10 | 441.49 |
| 24 | 610 | 9.53 | 141.12 | 12.70 | 187.06 | 6.35 | 94.53 | 9.53 | 141.12 | 14.27 | 209.64 | 17.48 | 255.41 | 24.61 | 355.26 | 30.96 | 442.08 | 36.89 | 547.71 | 48.02 | 640.03 |

## Formula of Calculations Weight

- **Weight of S.S. Sheets & Plates ::**
  Length ( Mtrs ) X Width ( Mtrs ) X Thick ( MM ) X 8 = Wt. Per PC
  Length ( fit ) X Width ( Mtrs ) X Thick ( mm ) X ¾ = Wt. Per PC
- **Weight of S.S. Circle**
  Dia ( mm ) X Dia (mm ) X Thick ( mm ) / 160 = Gms. Per PC
  Dia ( mm ) X Dia (mm ) X Thick ( mm ) X 0.00000063 = Kg. Per PC.
- **Weight of S.S. Pipe**
  O.D. ( mm ) – W Thick ( mm ) X W.Thick ( mm ) X 0.0248 = Wt. Per Mtr.
  O.D. ( mm ) – W Thick ( mm ) X W.Thick ( mm ) X 0.00758 = Wt. Per Mtr.
- **Weight of S.S. Round Bar.**
  Dia ( mm ) X Dia (mm ) X 0.00623 = Wt. Per. Mtr.
  Dia ( mm ) X Dia (mm ) X 0.0019 = Wt. Per. Feet.
- **Weight of S.S. Square Bar**
  Dia ( mm ) X Dia ( mm ) X 0.00788 = Wt. Per. Mtr
  Dia ( mm ) X Dia ( mm ) X 0.0024 = Wt.Per. Feet.
- **Weight of S.S. Hexagonal Bar**
  Dia ( mm ) X Dia ( mm ) X 0.00680 = Wt. Per.Mtr
  Width ( mm ) X Dia ( mm ) X 0.002072 = Wt. Per Feet
- **Weight of S.S. Flate Bar**
  Width (mm ) X Thick ( mm ) X 0.00798 = Wt.Per Mtr.
  Width (mm ) X Thick ( mm ) X 0.00243 = Wt.Per Feet.
- **Weight of Brass Pipe / Copper Pipe**
  O.D. ( mm ) – Thick ( mm ) X Thick (mm ) X 0.0260 = Wt. Per Mtr.
- **Weight of Lead Pipe.**
  O.D. ( mm ) – Wt ( mm ) X Wt ( mm ) X 0.0345 = Wt. Per Mtr.
- **Weight of Aluminium Pipe**
  O.D. ( mm ) – Thick ( mm ) X Thick ( mm ) X 0.0083 = Wt.Per. Mtr.
- **Weight of Aluminium Sheet**
  Length ( Mtr ) X Width ( Mtr ) X Thick ( mm ) X 2.69 = Wt.Per PC
  Weight of plate in **Kg** = Volume of plate in **$m^3$** x Metal density in **$kg/m^3$**
  = [(Plate length in **m**) x (Plate width in **m**) x (Plate thickness in **m**)]x (Metal density in **$Kg/m^3$**)
- **MILD STEEL (MS)** SHEET
  WEIGHT (KGS) = LENGTH (MM) X WIDTH (MM) X 0. 00000785 X THICKNESS
- **MS SQUARE**
  WEIGHT (KGS ) = WIDTH X WIDTH X 0.00000785 X LENGTH.
- **MS ROUND**
  WEIGHT (KGS ) = 3.14 X 0.00000785 X ((diameter / 2)X( diameter / 2)) X LENGTH.
- **SS ROUND**
  DIA (mm) X DIA (mm) X 0.00623 = WEIGHT PER METRE

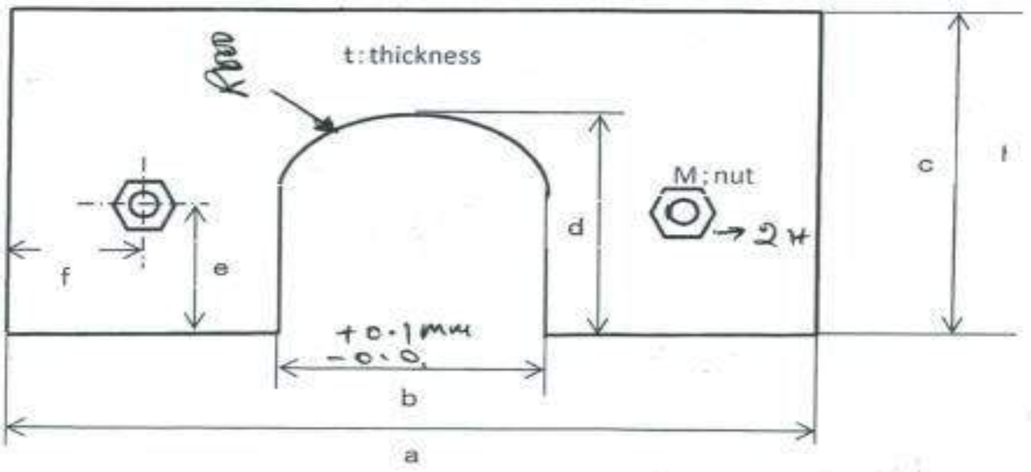
- **SS / MS Pipe**
  OD ( mm) – W.Tthick(mm) X W.Thick (mm) X 0.0248 = Weight Per Metre
  OD ( mm) – W.Tthick(mm) X W.Thick (mm) X 0.00756 = Weight Per Foot
- **SS / MS CIRCLE**
  DIA(mm) X DIA (mm) X THICK(mm) 0.0000063 = Kg Per Piece
- **SS sheet**
  Length (Mtr) X Width (Mtr) X Thick(mm) X 8 = Weight Per Piece
  Length (ft) X Width (ft) X Thick(inch) X 3 /4 = Weight Per Piece
- **S.S HEXAGONAL BAR**
  DIA (mm) X DIA (mm) X 0.00680 = WT. PER Mtr
  Dia (mm) X Dia (mm) X 0.002072 = Wt. Per foot.
- **BRASS SHEET**
  WEIGHT (KGS) = LENGTH (MM) X BREADTH (MM) X 0. 0000085 X THICKNESS
- **COPPER SHEET**
  WEIGHT (KGS) = LENGTH (MM) X BREADTH (MM) X 0. 0000087 X THICKNESS
- **BRASS / COPPER PIPE**
  OD (mm) – THICK (mm) X THICK(mm) X 0.0260 = WEIGHT PER METRE
- **ALUMINUM SHEET**
  WEIGHT (KGS) = LENGTH (MM) X BREADTH (MM) X 0. 00000026 X THICKNESS
- **ALUMINIUM PIPE**
  OD (mm) – THICK(mm) X THICK(mm) X0.0083 = WEIGHT PER METRE

## Puller bracket:



[mm]

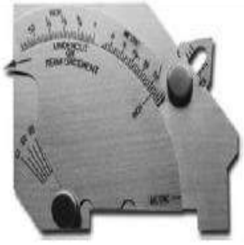
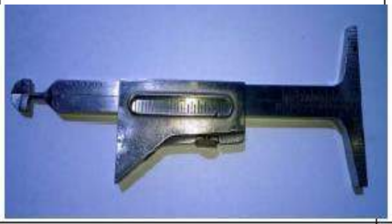
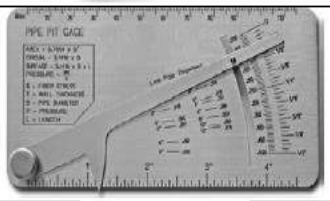
| 数量 | A | B | C | D | E | F | t1 | t2 |
|---|---|---|---|---|---|---|---|---|
| 2 | 450 | 170 | 100 | 5~~0~~5 | 23 | 16 | 16 | 50 |
| 2 | 300 | 100 | 100 | 5~~0~~5 | 23 | 16 | 16 | 50 |
| 2 | 220 | — | — | 50 | 18 | 16 | 16 | 50 |



QTY [mm]

| 数量 | a | b | c | d | e | f | M | t |
|---|---|---|---|---|---|---|---|---|
| 2 | 300 | 152 | 250 | 200 | 125 | 35 | M20 | 19 |
| 2 | 300 | 142 | 250 | 200 | 130 | 35 | M20 | 19 |
| 2 | 300 | 132 | 250 | 200 | 135 | 35 | M20 | 19 |
| 2 | 300 | 122 | 250 | 200 | 140 | 35 | M20 | 19 |
| 2 | 300 | 112 | 250 | 200 | 145 | 35 | M20 | 19 |
| 2 | 250 | 102 | 200 | 150 | 100 | 35 | M20 | 19 |
| 2 | 250 | 92 | 200 | 150 | 105 | 35 | M16 | 16 |
| 2 | 200 | 82 | 200 | 150 | 110 | 35 | M16 | 16 |
| 2 | 200 | 71 | 150 | 100 | 65 | 30 | M16 | 16 |
| 2 | 200 | 61 | 150 | 100 | 70 | 30 | M16 | 16 |
| 2 | 200 | 51 | 150 | 100 | 75 | 30 | M12 | 12 |
| 2 | 200 | 41 | 150 | 100 | 80 | 30 | M12 | 12 |
| 2 | 200 | 31 | 150 | 100 | 85 | 30 | M12 | 12 |

## Various types of tools for inspection:

| Equipment | Picture | Typical Usage |
|---|---|---|
| Flash Lights (Krypton) | | Supplemental light source for visual inspection. |
| Tape Measures 5' | | Dimensional inspection |
| Bridge Cam Gages |  | Multi-purpose welding inspection gage |
| Hi LO Gages |  | Measures internal alignment for components to be welded. |
| Radiograph Viewer 4" x 17" | | Light source for reviewing radiographic film |
| Radiograph Film Densitometer | | Tool designed to measure the degree or density of darkness of radiographic film. |
| Digital Calliper | | Instrument used to measure distance between opposite sides of an object. Typically used for close tolerance dimensions on machined parts. |
| OD Micrometer | | Instrument used to measure outside diameters/dimensions. Typically used for close tolerance dimensions on machined parts. |
| Pit gage |  | Measures the depth of weld undercut or other surface discontinuities. |
| Inspection Mirrors | | Tool designed to support visual inspection in limited and/or obscured areas. |

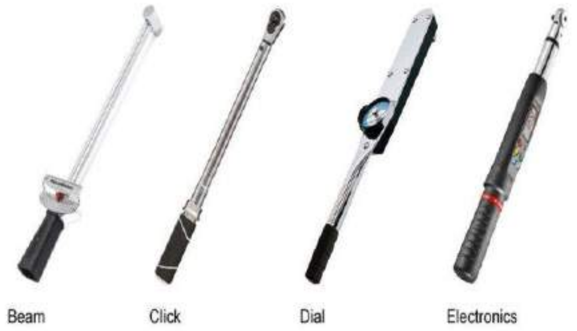
| | | |
|---|---|---|
| Temperature Indicator | | Used for reading temperatures by changing from solid to liquid at a specific temperature. |
| Laser Thermal Gun | | Tool for measuring surface temperature. |
| Clamp on Amp Meter | | Tool designed to measure electric current in amperage and voltage. May be used for checking welding machine settings. |
| Digital Surface Profile Gage | | Tool designed to measure the surface roughness for material that is about to be coated. |
| Surface Profile Replica Tape | PRESS-O-FILM<br>No.<br>Mils<br>3.5<br>Gage less 2.0<br>Testex<br>X COARSE (1.5-4.5) | Tool designed to replicate surface profile and measure surface roughness. |
| Wet Gauge | WET FILM THICKNESS GAUGE<br>DIRECTIONS FOR USE | Tool for measuring un-cured thickness of coating. |
| Camera | | Tool for photgraphic record keeping. |
| Magnifying Glass | | Tool for enhanced visual inspection. |
| Positive Material Identification Tool | | Tool designed to verify or measure chemical content. |
| Ferrite Meter | | Tool to measure the ferrite (iron phase) content in stainless steels. |
| Portable Brinell Tester | | Tool for measuring surface hardness. |

| | | |
|---|---|---|
| Vibration Meter | | Tool designed to measure mechanical oscillations. |
| Borescope | | Designed for remote visual inspection. |
| Liquid Penetrant Kit | | NDE technique for finding discontinuities open to the surface. |
| Ultrasonic Thickness Meter | | Tool commonly used for measuring metal thickness. |
| Vacuum Box | | Tool for measuring leakage in welded components |
| Ultrasonic Flaw Detection | | Volumetric NDE method for finding weld flaws. |
| Inside Micrometer Set | | Used for measuring inside diameters. |
| Magnetic Particle Testing | | Tool designed to detect surface and near surface discontinuities in ferrous materials. |
| Level | | Device used to determine horizontally level and/or vertically plumb |

| | | |
|---|---|---|
| Depth Micrometer | | Used for measuring depth. |
| Precision Gage Blocks | | Used for callibration of precision measurement equipment. |
| Bore Gage | | Measures inside diameter of components. |
| Machinists' Level with Ground and Graduated Vial | | Device used for precision verification of level of machines and components |

- **What is torque wrench?**

**Torque wrench** is a tool used to precisely apply a specific torque to a fastener such as a nut or bolt. It is usually in the form of a socket wrench with special internal mechanisms. It was designed to prevent over tightening bolts / studs



SET
UNLOCK
LOCK

- **What is the difference between bolt tensioning & bolt torquing give in detail??**

Bolt and nut combinations need to be "stretched" in order to provide a clamp effect across the joint. "Bolt Torquing" stretches the bolt as the nut is turned by a wrench. The more the nut is turned, the further it rides up the bolt's threads. Since it can't extend into the joint, the nut "pulls" the bolt, thus "stretching" it. "Bolt Tensioning" uses a tensioning tool to pull the bolt until the required stretch has been achieved. The nut is then turned freely by hand until it rests against the joint face. The tensioning pressure is then released. The applied stretch is retained mechanically by the nut.
Since friction has an effect on how easily a nut can be turned against a joint's face when torque, "Torturing" is much less accurate than "Tensioning" (in which friction is moot).
In bolt tensioning basically Stud is tensioned & nut is tightened by hand pressure. In torque tightening Nut is turned by means of torque tightening machine

- **What is the difference between torqueing of CS and SS bolting?**

Yield strength and torque values are greater in CS than SS.

**WHAT IS PULSATION DAMPENER**

Pulsation dampeners (accumulators, surge suppressors) are used to control and minimize the pulsations that result from a pressurized system's stroking action. They increase system efficiency, performance, and positive displacement pump life; decrease maintenance costs and down-time; and protect pipes, meters, valves and instrumentation from pulsation, vibration, and hydraulic shock.

Most pulsation dampeners use a bladder or bellows to separate the process fluid from a compressible gas. During the pump's discharge stroke, fluid pressure displaces the bladder or bellows and compresses the trapped gas. During the following cycle, the momentary interruption of fluid flow causes the compressed gas to expand, forcing the bladder or bellows to push the accumulated fluid back into the discharge line.

**Types**

- ✓ **Adjustable** dampeners can be set or tuned to accommodate different pressure ranges and response rates.
- ✓ **Automatic** dampeners use a valve in the device's non-wetted section to allow increases in air pressure to balance increases in liquid pressure.
- ✓ **Chargeable** dampeners fill a chamber with compressed air or nitrogen gas to create a cushion that absorbs pressure pulses within the system.
- ✓ By contrast, **liquid-filled** pulsation dampeners use a fluid-filled cavity to smooth the system.
- ✓ **Suction-lift** dampeners provide a stabilizer on the inlet side of the pump to reduce acceleration and ensure even pump feeding.
- ✓ **Pressure snubbers** are positioned before a pressure gauge to provide protection against pulsations in the measured media.

**Specifications :** Specifications for pulsation dampeners include maximum pressure, capacity, inlet size, and inlet type. Many suppliers specify maximum pressure in pounds per square inch (psi) and capacity in cubic inches ($in^3$). Inlet size is usually expressed in inches (in).

**There are several inlet types for pulsation dampeners**.

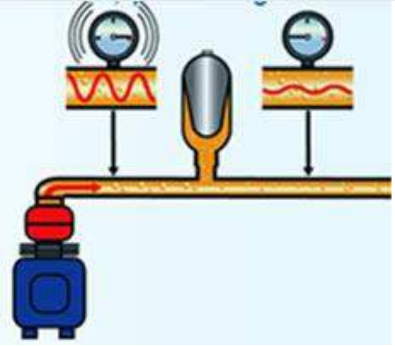
- ✓ **Flanged** inlets have multiple bolt holes for mounting to a mating flange.
- ✓ **Threaded** inlets have a threaded connection, usually a pipe thread.
- ✓ **Tri-clamp** dampeners have a specially configured flange that fits a clamp.

**Materials :** Pulsation dampeners use bladders or bellows made from a variety of materials.

- ✓ **Buna-N** provides good resistance to petroleum hydrocarbons and fuels.
- ✓ **Ethylene propylene** (EPDM) offers good resistance to sunlight, weather and ozone.
- ✓ **Chlorosulfonated polyethylene** (CSM) provides excellent resistance to ozone, oxidation, sunlight, and weathering.
- ✓ **Neoprene** is used over a wide temperature range and displays outstanding physical toughness.
- ✓ **Polyvinyl chloride** (PVC) has good flexibility, a smooth surface, and nontoxic qualities. Because of its inert nature, some PVC grades are used in food and chemical handling applications.
- ✓ **Polytetrafluoroethylene** (PTFE) is an insoluble compound that exhibits a high degree of chemical resistance and a low coefficient of friction.
- ✓ **Silicones** are polymers that provide heat, cold, and weather resistance; electrical insulation; good release; and water repellency.

## HOW DOES A PULSATION DAMPENER WORK?

A pulsation dampener creates an area of low pressure in the system with enough volume to absorb the pulsation. The pulsation dampener has a membrane with a "cushion" of compressible gas/air behind it that flexes to absorb the pulse, allowing a laminar flow downstream of the dampener.



## WHERE ARE PULSATION DAMPENERS COMMONLY USED?

Pulsation dampeners are commonly used wherever a positive displacement pump discharges flow in an unsteady manner, and where the pulse is not desired for the piping system. Air operated double diaphragm, metering and hose/peristaltic pumps typically benefit from a pulsation dampener.
The type of pulsation dampener used is typically defined by where they are placed in the system, and what they need to do. For example, "pulsation dampeners" are on the downstream side of the pump, "inlet stabilizers" are on the inlet side of the pump, and an accumulator or "surge suppressor" is used next to a valve or other device that restricts the flow in a system.
Figure shows where you would place an inlet stabilizer, and how it is used to reduce the pulsation with an air operated diaphragm pump in suction lift conditions.

- **What is centrifuge? Why it is used?**
  A centrifuge is a device for separating two or more substances from each other by using centrifugal **force**. Centrifugal force is the tendency of an object traveling around a central **point** to continue in a linear **motion** and fly away from that central point
- **What is the difference between Buna and Viton?**
  Buna-N is a common trade name for nitrile rubber, while Viton is a trade name for Fluorocarbon rubber. Viton has better chemical and temperature resistance than Buna, but Buna is usually less expensive. The exception is applications involving ammonia gas, where Buna has superior resistance to attack. Better to choose the Viton for most applications.
- **What is flushing fluid?**

Flushing fluid is light oil that can be used to help flush contaminants out of the pump / engine between oil changes. The general procedure is to drain the old oil, then refill the pump with flushing fluid. Run the pump for at least 10 minutes with the flushing fluid, and then drain again. Finally, refill the pump with fresh oil before installing.

- **Why we use kg/cm2 in pressure gauge not kg/m2 ?** if you take pressure in kg/m2 then it will be pressure digit will be reduced 100 times less, suppose you measured a pressure on gauge that 10kg/cm2 then it will be .0001 kg/m2.its depends upon you which will easier for you but never forget kg/cm2 is a standard unit for pressure
- **What is the unit of surface roughness?** micro inches Or micromilimeters

- **Difference between strength and toughness?**
  **Strength**:-resistive property of a material against the deformation.
  **Toughness**: energy stored in a material up to the breaking point.
- **What is the difference between stress and pressure?**
  **Stress**: It is the internal resistance per unit cross sectional area. Any body produces resistance to the external thrust acted upon it. E.g. Columns under the beam.
  **Pressure**: It is the force exerted per unit area. E.g. atmospheric pressure on earth.
- **What do you call a piston travel from TDC to BDC?** suction stroke or stroke length
- **What is flashpoint?** it is a temperature at which a fluid just gives a momentary flash
- **What is pour point?** it is a temperature at which the fluid has the ability to flow
- **What is fuel oil viscosity, specific gravity?**
  **Viscosity** is a frictional force between two layers.
  **Specific gravity** is the ratio of the density (mass of a unit volume) of a substance to the density (mass of the same unit volume) of a reference substance.
- **What are the causes of main engine black smoke?** Mostly it causes of due to failure of engine piston rings or added impurity in fuel which does not burn properly.
- **How catalyst converter works?** In chemistry, a catalyst is a substance that causes or accelerates a chemical reaction without itself being affected. Catalysts participate in the reactions, but are neither reactants nor products of the reaction they catalyze.
- **What the difference is between: throttle valve, flow control valve, venture?** throttle valve is a choking which is used for regulate of power of engine by supply of fuel, and venture valve is a nozzle through which fluid flow, and control valve is used for control of supply at inlet or outlet
- **What is an EN Material? What is the difference of EN8, EN24, and EN40?** EN mean European norms (British standard) generally EN8, EN24,EN40 use in round bar designation, and chemical composition difference between them, Medium carbon steel –MAGNETIC material.
- **Difference between strength & hardness?** **Strength** of a material indicates that how many types of restriction forces can be afford by the material. E.g. How many types of forces & how much force can be bearded. But, **hardness** is the property of material which restricts to scratch the surface. Hardness is the ability of a material to resist penetration through indentation. Strength is ability of a material to resist withstanding a load without failure.
- **What is the advantage of hermetically sealed compressor and rotary compressor**
  Power consumption and efficiency of hermetically compressor is better than rotary compressor. **1)** to reduce the noise & **2)**no refrigerant leakage

- **What is the difference between stress and pressure although both have same unit.**

**Pressure** is measured in close system where as **stress** is build on system. Pressure is acting under the system, stress acting on the system.

- **Define thermostat and thermocouple**

**Thermocouple:** it is formed by joining two dissimilar metals and maintained at two different temperatures. This difference in temperature creates an electro motive force at the junction. This is the principle used behind the thermocouple .an example for thermocouple is chrome- aluminum thermocouple
**Thermostat:** it is a temperature controlling device. By which we can set any temperature. This is done by controlling the fluid which transfers the heat. This contains temperature sensors. The output of temperature sensors are used to vary the temperature

- **What is the thermodynamic?** Thermo- heat; dynamics- moving or transfer substances. Study of heat, while it is in motion or to be transferred.
- **What is carburetor?** carburetor is a device which provide sufficient amount fuel and air mixture

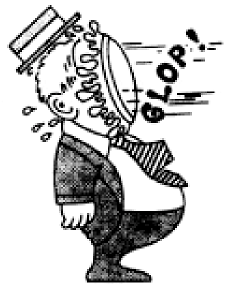
- **What is difference between absorption, adsorption and desorption?**

**Absorption** It is a chemical reaction between an absorbent and the material to be absorbed. Hence it is a process by which a material is absorbed by a liquid by chemical reaction.

**Adsorption** It is a physical phenomenon by which an absorbent gets adsorbed by a media not chemically but physically only.

**Desorption** It is reverse of Adsorption, means release of an absorbed material

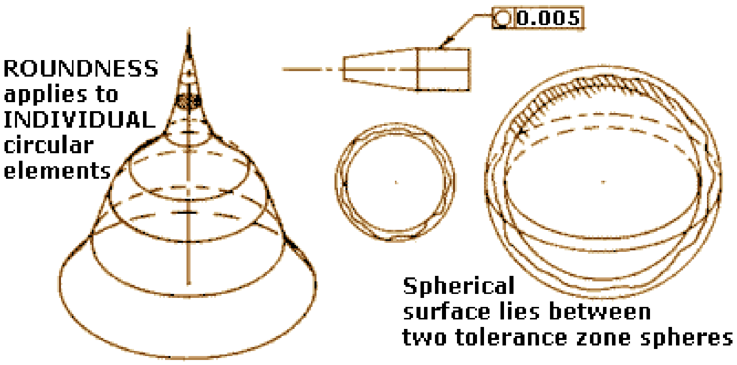
ABsorption



ADsorption

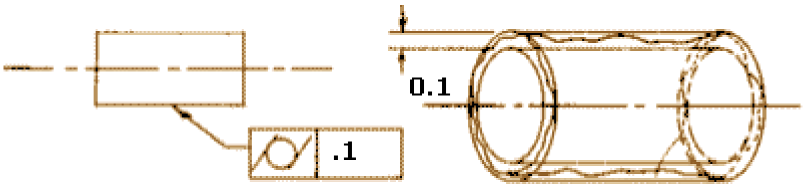
- **Difference between roundness, cylindricity, concentricity, circular run out, and total run out?**

**ROUNDNESS:** As shown in Figure, roundness applies to individual circular cross sections of a surface of revolution or of a sphere.


ROUNDNESS applies to INDIVIDUAL circular elements
○ 0.005
Spherical surface lies between two tolerance zone spheres

**CYLINDRICITY:** on the other hand, applies to all cross-sections of a cylindrical surface simultaneously. The surface must lie between the two cylindrical surfaces which bound the tolerance zone and are determined by a best-fit nominal cylinder. Figure illustrates cylindricity.

**Figure: CYLINDRICITY applies to all cross-sectional elements simultaneously.**

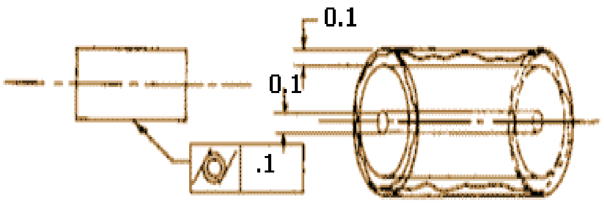


It is a common misconception that roundness and cylindricity can be checked by taking diametral measurements (as with a micrometer) or by using an indicator and vee block. A diametral measurement does just what the words imply; it measures the diameter. It does not check the shape of the surface which is what roundness and cylindricity control. Since the roundness or cylindricity tolerance is a radial distance between concentric boundaries, a radial method of checking the surface is necessary. However, rotating a part between centers is not an acceptable method since it relates the part surface to an axis, which technically is a check of another geometric tolerance called runout.

To truly check for the roundness or cylindricity of a surface without regard to the axis of the part, the part must be rotated about the ultra-precision spindle of a specialized roundness measuring machine. A probe contacts the surface and transcribes an enlarged profile of the surface onto a polar graph. The profile is then checked against a clear overlay of concentric circles to determine if it falls within the allowable tolerance zone.

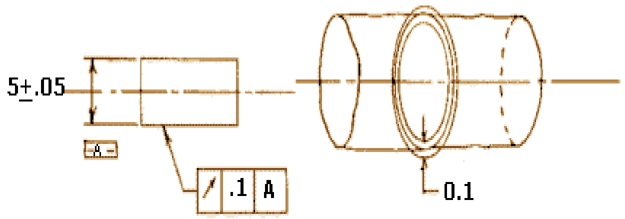
**CONCENTRICITY:** Concentricity is the condition in which the axes of all cross-sectional elements of a surface of revolution are common to the axis of a datum feature. Because the location of the datum axis is difficult to find, it is easier to inspect for cylindricity or runout.

**Figure: CONCENTRICITY is based upon the datum axis so that it is difficult to ascertain.**



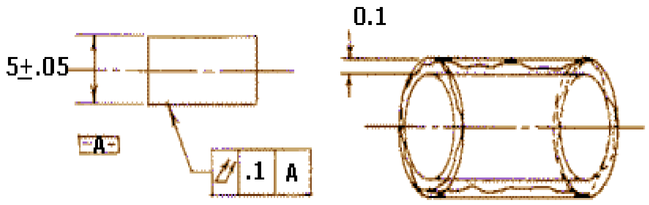
**CIRCULAR RUNOUT :** Runout refers to the result of placing a solid of revolution on a spindle such as a lathe, and rotating the part about its central axis while measuring with a dial indicator its surface deviation from perfect roundness. With circular runout, the dial indicator is not moved along the direction of the axis of the part. Circular runout is therefore applied independently at each station along the length of the part as the part is rotated through 360 degrees.

**Figure: CIRCULAR RUNOUT applies to each cross section individually.**



**TOTAL RUN OUT :** Total run out involves moving the dial indicator along the length of the part while the part is rotated, so that it controls the cumulative variations of circularity, cylindricity, straightness, coaxiality, angularity, taper, and profile.

**Figure: TOTAL RUNOUT applies to all cross sections simultaneously.**



The absolute value of highest to lowest gauge reading is often called "TIR," or "total indicator reading." FIM," which is "full indicator movement." It essentially means the same thing — the total variation from highest to lowest gauge point.

- **What is difference between circular run out and total run out?**

The difference between circular and total run out tolerances is that circular run out tolerances only apply to each cross-section separately while total run out is measured over the entire feature.
Run out tolerances are usually applied to parts that rotate around an axis of rotation which Constitutes datum and can generally be described as a tolerance for how much a surface may vary during one revolution.

- **Every material has two types of frequencies:**

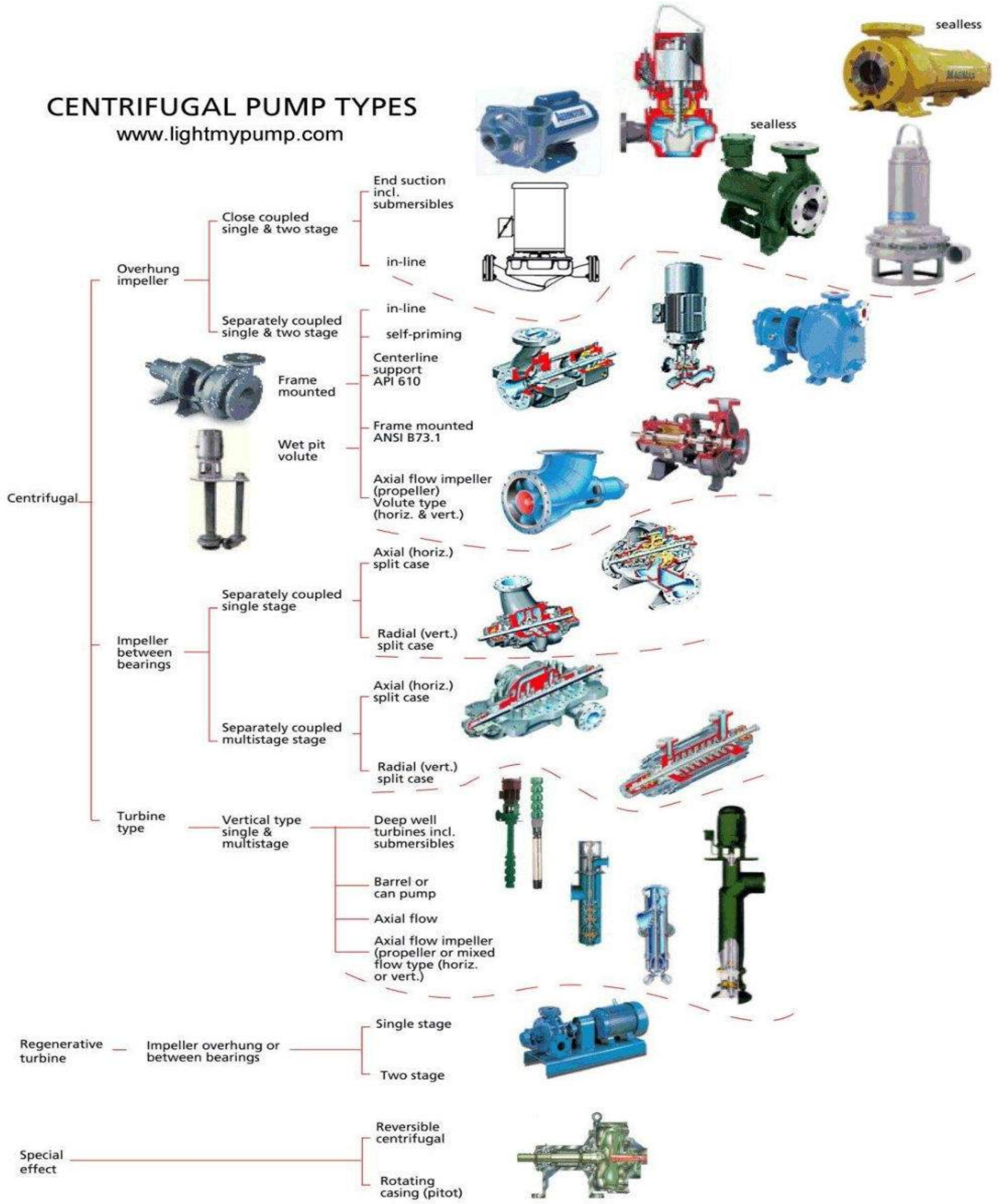
1. **Natural Frequency**: Natural frequency is the frequency present in any material owing to its atomic structure.
2. **Forced Frequency**: Forced frequency is the frequency produced by the material, when an external force acts on it. If at some instances, the forced frequency matches with natural frequency, the resulting frequency is going to be very high compared to individual frequencies. This phenomenon is known as **resonance**.

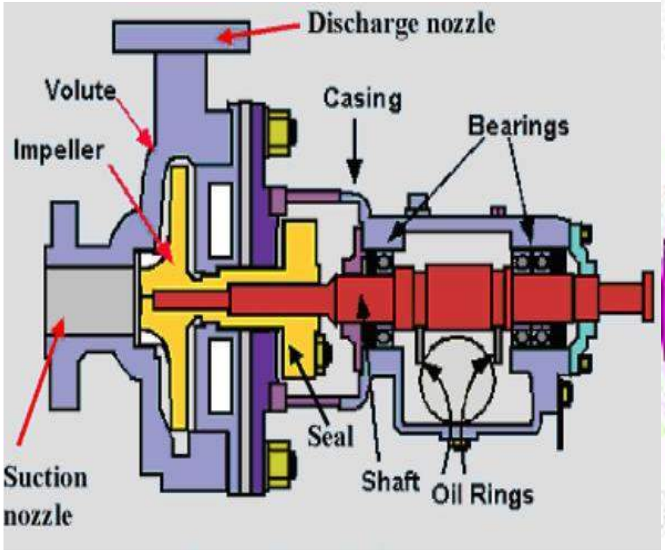
**Critical speed** is defined as the speed of equipment at which its natural frequency coincides with its forced frequency, resulting into resonance condition. At critical speed, vibrations induced in the equipment or material are very high (due to resonance ) and if this condition is allowed to continue for longer period, material may develop fracture or permanent stresses and strains. All materials have critical speeds; Critical speed depends upon following dimension: Length, Breadth and Weight

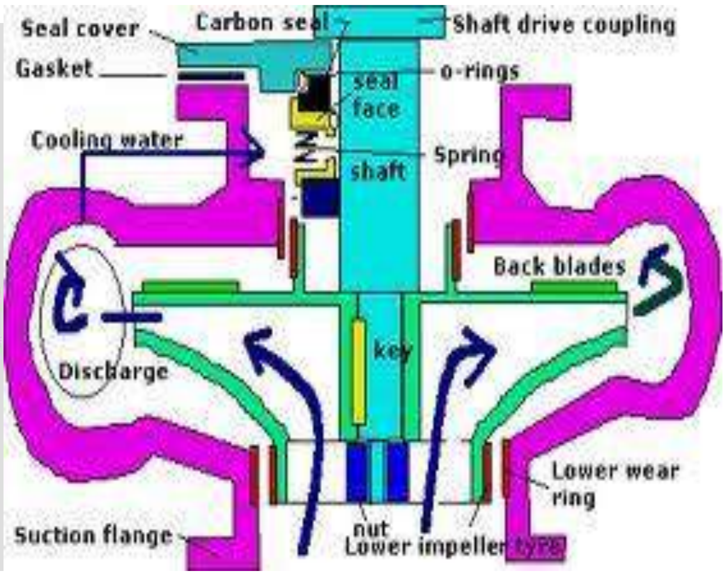
If some parameters of above dimensions are altered, the critical speed of the material also changes. A material has many critical speeds. While designing a rotor/shaft for machine, the designer makes sure that the critical speed doses not fall within the operating range of the machine. The dimensions of the rotor/shaft are accordingly adjusted. In the case of machines operated by motors, the speed of the rotor reaches the normal speed within a short time. But in the case of turbines, where the speed has to be increased in small increments, critical speeds are encountered. In such cases, therefore, manufacturer mentions the critical speed ranges and accordingly running the equipment at these critical speeds should be avoided.

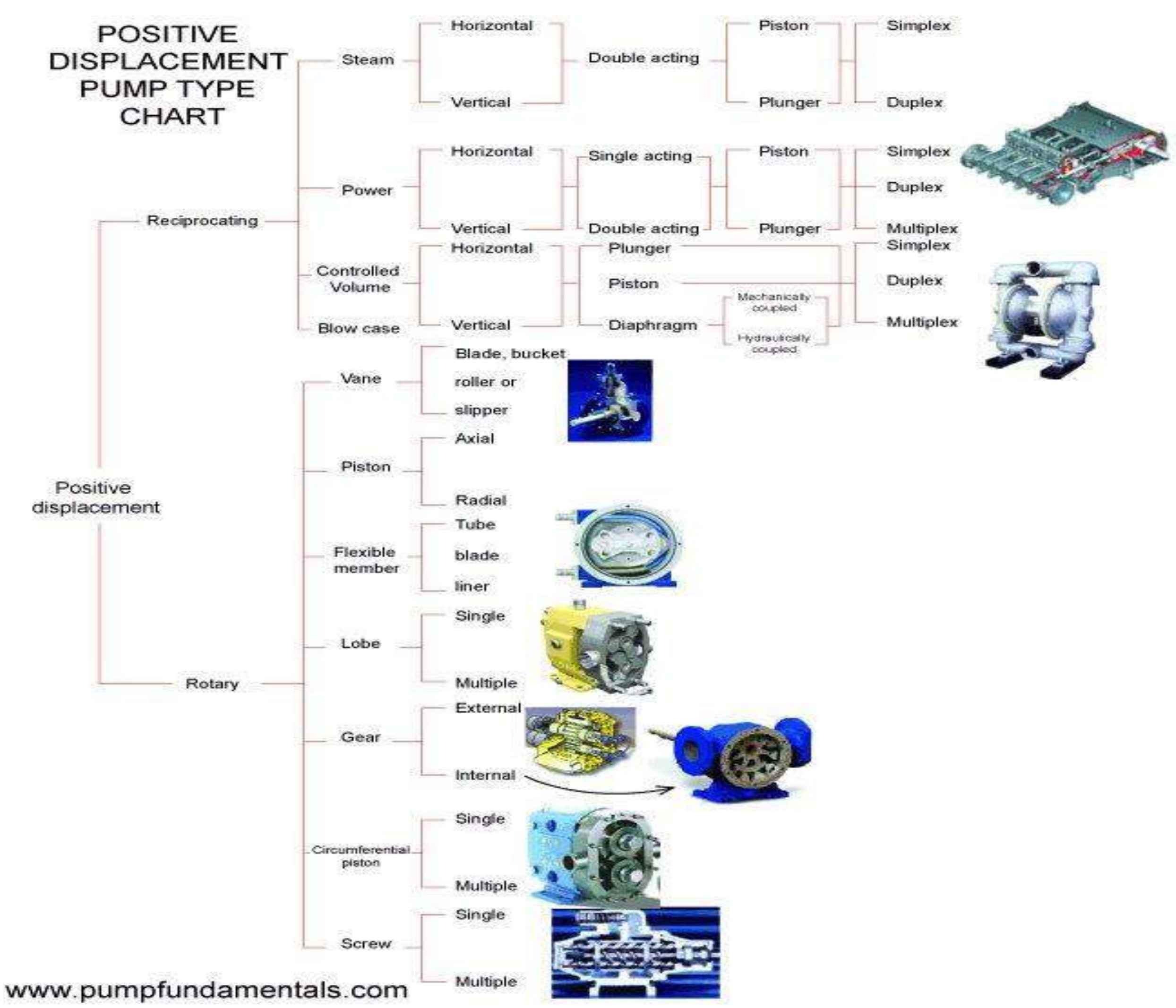
# PUMPS

## Types of Pumps


CENTRIFUGAL PUMP TYPES
www.lightmypump.com
Centrifugal
Overhung impeller
Close coupled single & two stage
End suction incl. submersibles
in-line
Separately coupled single & two stage
in-line
self-priming
Frame mounted
Centerline support API 610
Wet pit volute
Frame mounted ANSI B73.1
Axial flow impeller (propeller) Volute type (horiz. & vert.)
Impeller between bearings
Separately coupled single stage
Axial (horiz.) split case
Radial (vert.) split case
Separately coupled multistage stage
Axial (horiz.) split case
Radial (vert.) split case
Turbine type
Vertical type single & multistage
Deep well turbines incl. submersibles
Barrel or can pump
Axial flow
Axial flow impeller (propeller or mixed flow type (horiz. or vert.)
Regenerative turbine
Impeller overhung or between bearings
Single stage
Two stage
Special effect
Reversible centrifugal
Rotating casing (pitot)
sealless
sealless


Discharge nozzle
Volute
Casing
Bearings
Impeller
Seal
Shaft
Oil Rings
Suction nozzle


Seal cover
Carbon seal
Shaft drive coupling
Gasket
o-rings
seal face
Cooling water
Spring
shaft
Back blades
Discharge
key
Lower wear ring
Suction flange
nut
Lower impeller type


POSITIVE DISPLACEMENT PUMP TYPE CHART
Positive displacement
Reciprocating
Steam
Horizontal
Vertical
Double acting
Piston
Plunger
Simplex
Duplex
Power
Horizontal
Vertical
Single acting
Double acting
Piston
Plunger
Simplex
Duplex
Multiplex
Controlled Volume
Blow case
Horizontal
Vertical
Plunger
Piston
Diaphragm
Mechanically coupled
Hydraulically coupled
Simplex
Duplex
Multiplex
Rotary
Vane
Blade, bucket
roller or
slipper
Piston
Axial
Radial
Flexible member
Tube
blade
liner
Lobe
Single
Multiple
Gear
External
Internal
Circumferential piston
Single
Multiple
Screw
Single
Multiple

www.pumpfundamentals.com

**There are mainly two types of pumps:**

**1. Positive displacement Pumps**

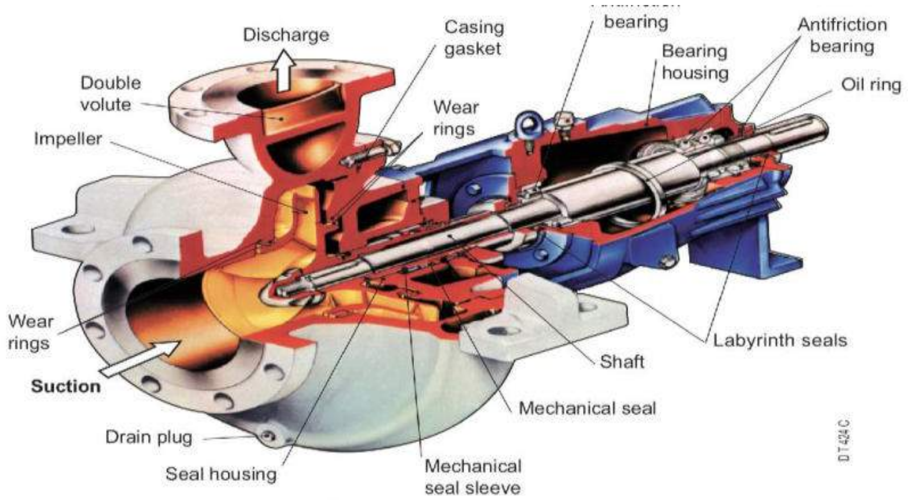
A Positive displacement pump pushes a positive or specific volume of fluid in each pumping cycle.

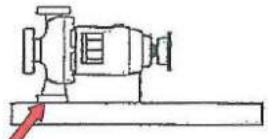
**2. Centrifugal Pumps**

A Centrifugal pump increases the pressure of a liquid passing through it by increasing its velocity.

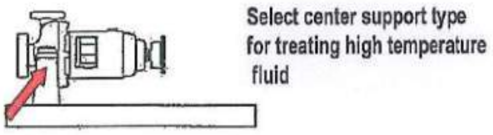
**Centrifugal Pump**

In centrifugal pumps, the energy supplied by an electric motor or steam turbine is transferred to the liquid being pumped by rotating an impeller. The rotation of the impeller supplies velocity (velocity is the speed at which something moves in one direction) or movement to the incoming liquid. The pump casing (diffuser and volute) converts part of this velocity energy in to pressure energy.

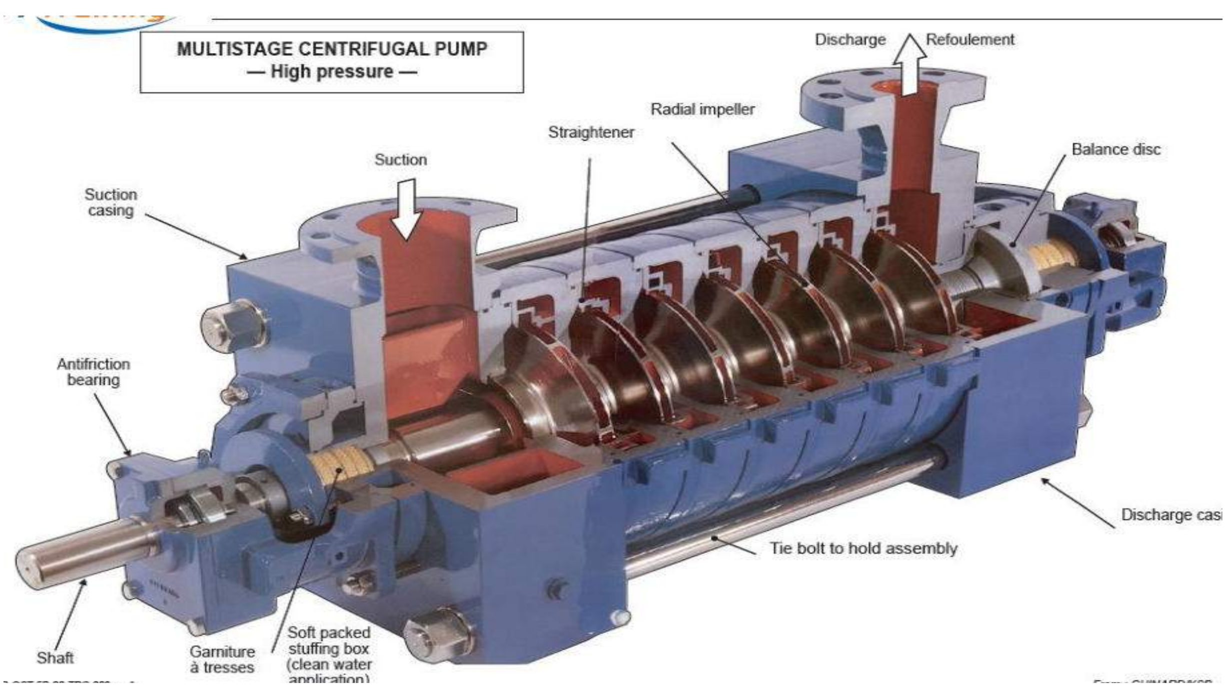

Discharge
Casing gasket
bearing
Antifriction bearing
Bearing housing
Oil ring
Double volute
Impeller
Wear rings
Wear rings
Suction
Drain plug
Seal housing
Mechanical seal sleeve
Mechanical seal
Shaft
Labyrinth seals
DT 424 C



Foot mounted


Select center support type
for treating high temperature
fluid

Centerline mounted


MULTISTAGE CENTRIFUGAL PUMP
— High pressure —
Discharge
Refoulement
Radial impeller
Straightener
Suction
Balance disc
Suction casing
Antifriction bearing
Discharge casi
Tie bolt to hold assembly
Shaft
Garniture à tresses
Soft packed stuffing box (clean water application)

## System Head

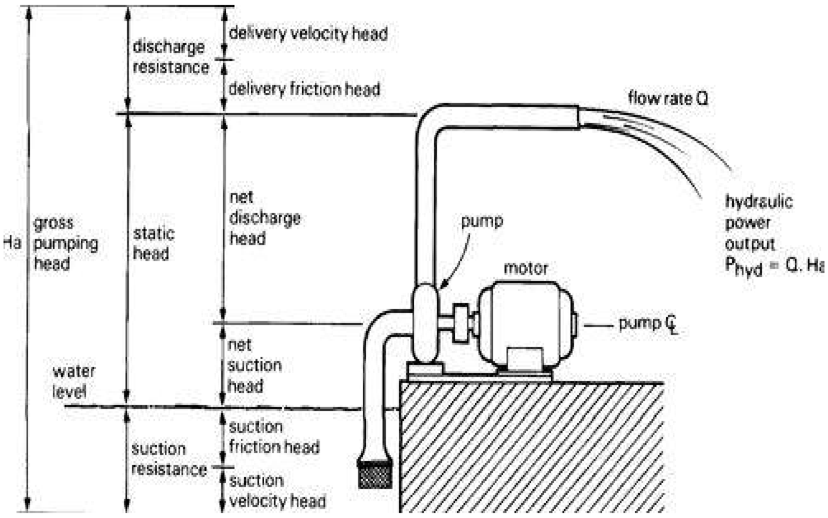
The work required to move one kg of liquid at the required flow rate from one point to another point is called System Head or total head of the system.

System head is related to total discharge head and total suction head by following equation:

**System Head** = (Total Discharge Head) – (Total Suction Head ) , System head is a measure of Pressure supplied by the pump to the liquid. Units: System head, Total suction head and Total discharge head are expressed in Meter of liquid (gauge or absolute unit).

**Total Suction Head or Net Suction Head** = Static suction head + Suction side liquid surface pressure head – Friction losses in the suction piping .Static suction head is the vertical distance measured from the free surface of the liquid to the centre line of the pump.

**Total Discharge Head or Net Discharge Head** = Static discharge head + Discharge side liquid surface pressure head – Friction head loss in the discharge line . Static discharge head is the vertical distance measured from the pump centerline to the free surface of the liquid in the discharge tank or point of free discharge.


delivery velocity head
discharge resistance
delivery friction head
flow rate Q
net discharge head
gross pumping head
Ha
static head
pump
hydraulic power output
$P_{hyd}$ = Q. Ha
motor
pump ℄
net suction head
water level
suction friction head
suction resistance
suction velocity head

## Static head

Static head is the difference in height between the source and destination of the pumped liquid .Static head is independent of flow. The static head at a certain pressure depends on the weight of the liquid and can be calculated with this equation: Head (in feet) = Pressure (psi) X 2.31 /specific gravity

## Friction head (hf)

This is the loss needed to overcome that is caused by the resistance to flow in the pipe and fittings. It is dependent on size, condition and type of pipe, number and type of pipe fittings, flow rate, and nature of the liquid. The friction head is proportional to the square of the flow rate. A closed loop circulating system only exhibits friction head (i.e. not static head).

**Net Positive Suction Head (NPSH)** Net positive suction head is the total net energy available at the suction pipe nozzle above the vapor pressure of the liquid, required maintaining the pump total head. NPSH is expressed as available NPSHa or required NPSHr .

## Pump Performance Curves

The performance characteristics of centrifugal pump are defined by its performance curves. The performance curves of a centrifugal pump are a set of curves of capacity vs. total head, NPSH, efficiency and horsepower. The performance curves of centrifugal pump are based on a particular speed, diameter of the impeller and viscosity of liquid.

### Total Head vs. Capacity Curves

Capacity of pump is the amount of liquid moved by the pump per hour or per minute and is expressed as $M^3/H$ or $M^3/Min$. Total head vs. capacity curve shows that as the capacity of pump increases, the total head developed by the pump decreases. The head developed by a pump will be maximum when the pump is running without any discharge flow i.e. pump is running with discharge valve closed (This is also known as '**pump shut off head'**)

### BHP(Brake Horse Power) vs. Capacity Curves

The power required by a pump to do a specified amount of work is known as BHP of the pump and is expressed in 'kilowatts' Brake horsepower or horsepower required by a centrifugal pump increases with an increase in capacity of the pump.

### Efficiency vs. Capacity Curves

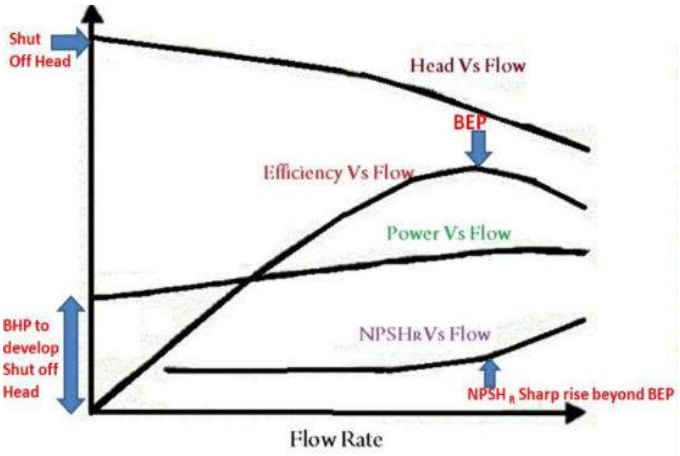
Efficiency of pump is a measure of various losses that are taking place during the pumping of a liquid. The efficiency of a centrifugal pump is relatively low at too high and too low discharge flow rates. For every pump, there is a capacity where the pump operation is most efficient i.e. efficiency is maximum, and therefore the economical.

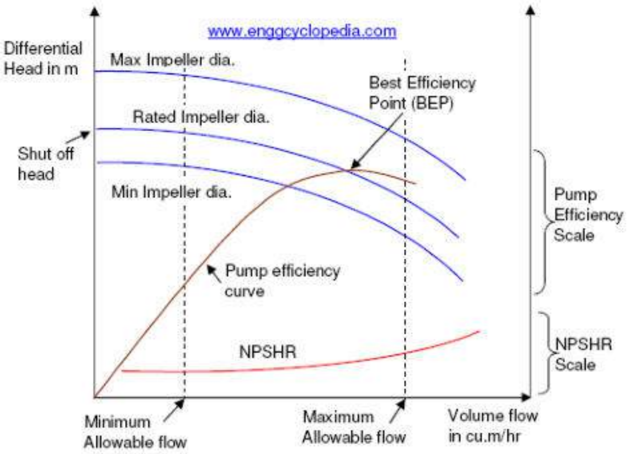
### NPSH vs. Capacity Curves

As the pumping rate increases, the $(NPSH)_{req}$ increases.

**Pump performance curve** The head and flow rate determine the performance of a pump, which is graphically shown in Figure (the performance curve or pump characteristic curve). The figure shows a typical curve of a centrifugal pump where the head gradually decreases with increasing flow.
As the resistance of a system increases, the head will also increase.

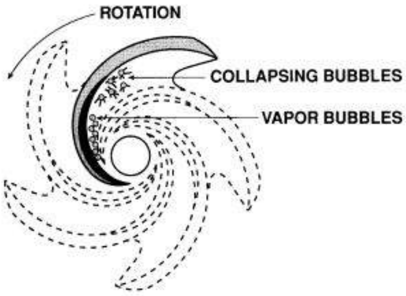
**Pump operating point:** The rate of flow at a certain head is called the duty point. The pump performance curve is made up of many duty points. The pump operating point is determined by the intersection of the system curve and the pump curve as shown in Figure

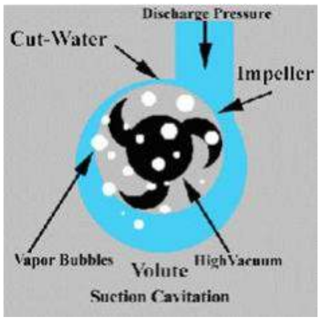




### Cavitation

This is the most encountered phenomena that occur in Pumps. When pump suction line pressure drops below the vapour pressure of the liquid being pumped i.e. if $(NPSH)_{av}$ is near or equal to minimum $(NPSH)_{req}$ liquid flashes to form vapours. These vapour bubbles collapse or break when they reach regions of high pressure (Discharge volute) inside the pump. This causes crackling noise and vibration in the pump. The rapid formation and collapsing of vapour bubbles inside the pump, with crackling noise and vibration is called Cavitation. During the Cavitation of the pump, flow and discharge pressure of pump will fluctuate continuously.





### Operating a pump under cavitation

Operating a pump under cavitation for a longer period is very harmful for pump and it will cause:
- Pitting and erosion of impeller or even on the casing of the pump
- Pump vibration may cause bearing failure or shaft deformation.

**Prevention of Pump Cavitation** Pump cavitation can be prevented during the operation of the pump by increasing $(NPSH)_{av}$.

### To increase $(NPSH)_{av}$ following methods can be used:

- ✓ Increase suction side (vessel or tank or column) liquid level.
- ✓ Throttle discharge valve of the pump to reduce pumping rate and thereby reduce $(NPSH)_{req}$.
- ✓ Cool the pump suction to suppress vapor formation.

## Minimum Flow For Pumps

Running a Centrifugal pump with **discharge valve in fully closed condition i.e. in shut off condition** for a longer duration leads to heating up of liquid inside the pump due to friction. Due to close circulation of the liquid in the pump, the generated heat keeps on accumulating. If the liquid being pumped is nearer to its boiling point or is having lower boiling point, then overheating of liquid may cause vapor binding of the pump. This may lead to serious process as well as mechanical problems of the pump. To prevent such overheating of the pump, a certain minimum flow should be maintained through the pump, whenever the pump is in operation. Minimum flow for any pump is calculated and recommended by the pump supplier. Minimum flow is also recommended for pumps with high discharge head or high capacity to minimize vibration in the pump.

**Pump Priming** : A pump with air in its casing / suction pipe is air bound and can't developed pressure until the air has been released / replaced by a liquid. Priming is an operation whereby we drive out or vent the air or Gas filled or trapped in the suction line and the casing of the pump by filling it with liquid to be pumped , The head developed by a centrifugal pump is same for all liquids of different densities. But the pump developed pressure varies with the density of liquid being pumped because, pressure = head × density.

## Why discharge valve is kept close before starting a centrifugal pump?

We know that according to Newton law of inertia "A body tends to remain in the state of rest or in a state of motion, when an external force is applied to it to change its state. So rotor of the pump in rest will try to remain in rest due to inertia. It is due to this reason that the motor draws huge current during kick off of the pump. If discharge valve is kept open before starting the pump, then the motor will have to take load of the pump as well as Inertia load and hence may draw excessive power and may lead to overheating of winding, electrical wires or even burning of them etc. It is due to this reason that discharge valve is kept close initially, pump is then started and when amperage reading comes down from red zone to green zone, and then only discharge valve is opened

## In which condition can we keep discharge valve open?

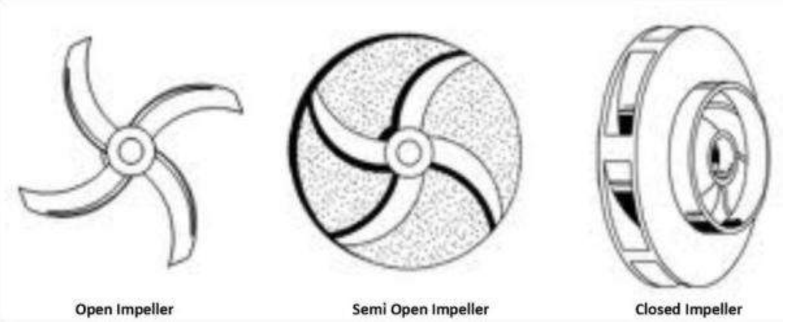
1. If pump is of small capacity. Normally, smaller the motor, higher is the reserve power it has. ( in big motors, the reserve power is 1.1 to 1.25 times the rated, while in small motors it can be between 1.5 to 2.0 times )
2. If Pump is allowed to start, having a back pressure available in discharge header. Like auto-start condition on Low Pressure or low flow on the standby pump
3. If motor has been ensured to have over design

## Components of a centrifugal pump

The main components of a centrifugal pump are described below:

- Rotating components: an impeller coupled to a shaft and bearings.
- Stationary components: casing, stuffing box

### a) Impeller



Impeller is the rotating part of pump which convert driver energy to kinetic energy (Kinetic energy is the energy of motion), provide centrifugal acceleration to the fluid. An impeller is a circular metallic disc with a built-in passage for the flow of fluid. Impellers are generally made of bronze, polycarbonate, cast iron or stainless steel, but other materials are also used. As the performance of the pump depends on the type of impeller, it is important to select a suitable design and to maintain the impeller in good condition. The number of impellers determines the number of stages of the pump. A single stage pump has one impeller and is best suited for low head (=pressure) service. A two-stage pump has two impellers in series for medium head service. A multi-stage pump has three or more impellers in series for high head service.

Impellers can be classified on the basis of:

- **Major direction of flow** from the rotation axis: radial flow, axial flow, mixed flow
- **Suction type**: single suction and double suction
- **Shape or mechanical construction:** closed , open and semi open

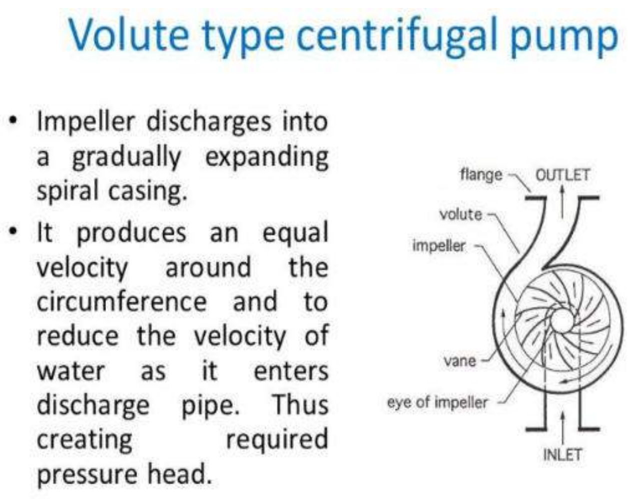
Closed impellers have vanes enclosed by shrouds (= covers) on both sides . This prevents liquid moving from the delivery side to the suction side, which would reduce the pump efficiency. In order to separate the discharge chamber from the suction chamber, a running joint is necessary between the impeller and pump casing. This joint is provided by wearing rings, which are mounted either over extended portion of impeller shroud or inside the cylindrical surface of pump casing.

A disadvantage of closed impellers is the higher risk of blockage. Open and semi-open impellers are less likely to clog. But to avoid clogging through internal re-circulation, the volute or back-plate of the pump must be manually adjusted to get the proper impeller setting. Closed impeller require wear rings, open and semi open impellers need adjustment with respect to volute or back plate to prevent internal circulation. Vortex pump impellers are suitable for solid and "stringy" materials but they are up to 50% less efficient than conventional designs.

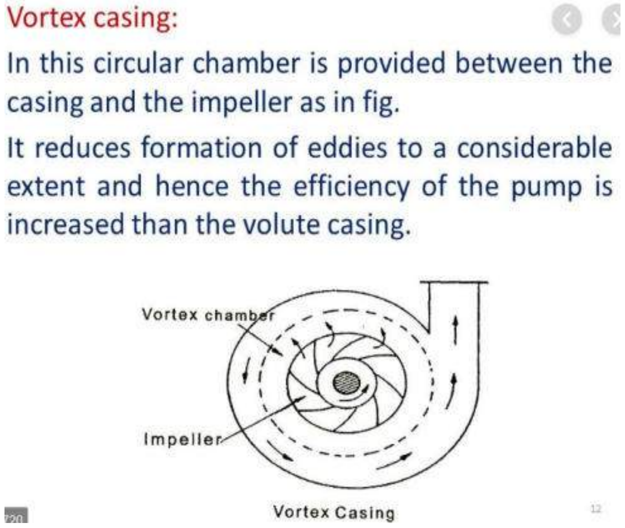
**b) Shaft :** The shaft transfers the torque from the motor to the impeller during the startup and operation of the pump.
**c) Casing :**The main function of casing is to enclose the impeller at suction and delivery ends and thereby form a pressure vessel. The pressure at suction end may be as little as one-tenth of atmospheric pressure and at delivery end may be twenty times the atmospheric pressure in a single-stage pump. For multi-stage pumps the pressure difference is much higher. The casing is designed to withstand at least twice this pressure to ensure a large enough safety margin.
A second function of casing is to provide a supporting and bearing medium for the shaft and impeller. Therefore the pump casing should be designed to provide easy access to all parts of pump for inspection, maintenance and repair

- Make the casing leak-proof by providing stuffing boxes
- Connect the suction and delivery pipes directly to the flanges
- Be coupled easily to its prime mover (i.e. electric motor / turbine) without any power loss.
- pump casing are normally two types - volute casing and vortex(circular) casing

**There are two types of casings**
**Volute casing** has impellers that are fitted inside the casings. One of the main purposes is to help balance the hydraulic pressure on the shaft of the pump. However, operating pumps with volute casings at a lower capacity than the manufacturer’s recommended capacity can result in lateral stress on the shaft of the pump. This can cause increased wearing of the seals, bearings, and the shaft itself. **Volute casings** are used when the radial force becomes significant at reduced capacities. Build higher head , a volute has curved funnel increasing cross section area towards discharge port , as the cross section area increase reduce the speed of liquid and eventually increase the pressure . **Main purpose of volute casing is to help balance the hydraulic pressure on the shaft of pump.**


Volute type centrifugal pump

- Impeller discharges into a gradually expanding spiral casing.
- It produces an equal velocity around the circumference and to reduce the velocity of water as it enters discharge pipe. Thus creating required pressure head.


Vortex casing:

In this circular chamber is provided between the casing and the impeller as in fig.

It reduces formation of eddies to a considerable extent and hence the efficiency of the pump is increased than the volute casing.

**Vortex /Circular casing** has stationary diffusion vanes surrounding the impeller periphery that convert speed into pressure energy. These casings are mostly used for multi-stage pumps has stationary diffusion vanes surrounding the impeller periphery that converts velocity energy into pressure energy.
The casings can be designed as:
− **Solid casing**: the entire casing and the discharge nozzle are contained in one casting or fabricated piece.
− **Split casing*:*** two or more parts are joined together. When the casing parts are divided by horizontal plane, the casing is called horizontally split or axially split casing.

- **Wear rings** : in the centrifugal pump , liquid obviously trend to leak from high pressure area ( discharge ) to low pressure area (suction),to prevent this annular space between casing and impeller eye is provided with the replacing ring called wear ring .
  There are two type of wear ring-one is casing wear ring and impeller wear ring , casing wear ring fitted on casing and impeller wear ring fitted on impeller . the radial clearance maintained between two rings in such a way that flow from discharge to suction side restricted substantially , if the wear ring clearance are increase pump capacity will decrease , **its recommended to replace wear ring when the clearances reaches the double.**
- **Stuffing box**: the pumped liquid is certainly going to leak from the place shaft enter to the pump casing . to prevent this leak stuffing box(when sealing is achieved by packing) / seal chamber ( when sealing is achieved by mechanical seal ),when the pressure below atmosphere in the casing its prevent air leakage into the pump & when the pressure increase above atmosphere its leakage out of the pump .
- **Lantern ring** : circular metal ring to cool and lubricate the packing

### Axial thrust and method to eliminate:

When pump in operational mode, many differential pressure developed within casing, axial thrust on shaft in the direction towards the suction, if axial thrust is not eliminated it can damage pump internal part. Therefore some method applied to balance axial load / thrust.

- Balancing hole: impeller eye region sometimes hole are provided, the discharge pressure of the liquid escape through these hole and goes to suction, in this way the pressure difference across impeller is minimized to zero.
- Impeller back vanes : in some cases impeller are provided with straight radial projection on the rear side of the shroud .these vanes try to throw pressurize liquid towards discharge nozzle , in this way the pressure difference substantially minimized that result balancing of axial thrust load . Impeller with back vanes are provided only with one wear ring on the suction side.

### ENERGY EFFICIENCY OPPORTUNITIES

Main areas for improving pumps and pumping systems. The main areas for energy conservation include:

- Selecting the right pump
- Controlling the flow rate by speed variation (VFD)
- Pumps in parallel to meet varying demand
- Eliminating flow control valve
- Eliminating by-pass control
- Start/stop control of pump
- Impeller trimming

### Impeller trimming

Changing the impeller diameter gives a proportional change in the impeller's peripheral velocity. Similar to the affinity laws, this option cannot be used where varying flow patterns exist. The impeller should not be trimmed more than 25% of the original impeller size, otherwise it leads to vibration due to cavitation and therefore decrease the pump efficiency. The balance of the pump has to been maintained, i.e. the impeller trimming should be the same on all sides. Changing the impeller itself is a better option than trimming the impeller, but is also more expensive and sometimes the smaller impeller is too small. Trimming involves machining the impeller to reduce its diameter. As the impeller diameter decreases, increases internal flow recirculation; causes head loss, and lowers pumping efficiency. Trimming reduces the impeller's tip speed, which in turn reduces the amount of energy imparted to the pumped fluid; as a result, **the pump's flow rate and pressure both decrease**

**Stuffing box pressure:** The pressure acting on the stuffing box which must be sealed.

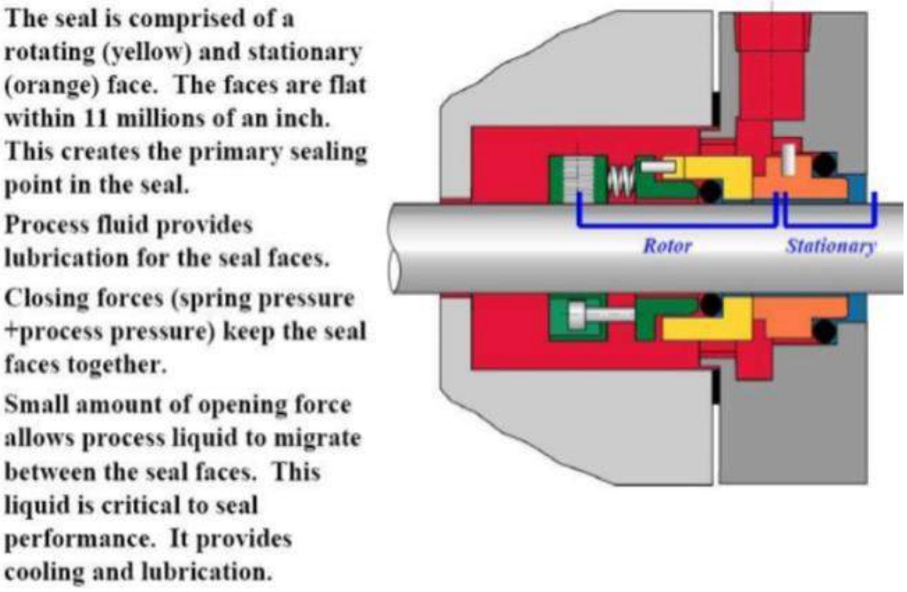
-It is a function of pump impeller design and the presence or condition of wear rings.

- **Impeller design and Stuffing box pressure**
  - Back vanes - Open impeller # Suction + 25% of differential P = Stuffing box pressure
  - Balance Holes - Closed impeller # Suction + 10% of differential P = Stuffing box pressure
  - Double Suction # Suction pressure = stuffing box pressure
    (Differential pressure = discharge pressure – suction pressure )

**Mechanical seal**: a name for the joint that seals the fluid in the pump stopping it from coming out at the joint between the casing and the pump shaft. A mechanical seal is a sealing device which forms a running seal between rotating and stationary parts. They were developed to overcome the disadvantages of compression packing.

### What is cartridge type of mechanical seal?

A cartridge type mechanical seal is a pre-assembled package of seal components making installation much easier with fewer points for potential installation errors to occur. A Cartridge Seal assembly is "pre-set" so that no installed length calculations must be performed for determining where to set the seal. Only the external seal in a double cartridge have "set tabs" that are removed once the seal is installed and the pump assembled.

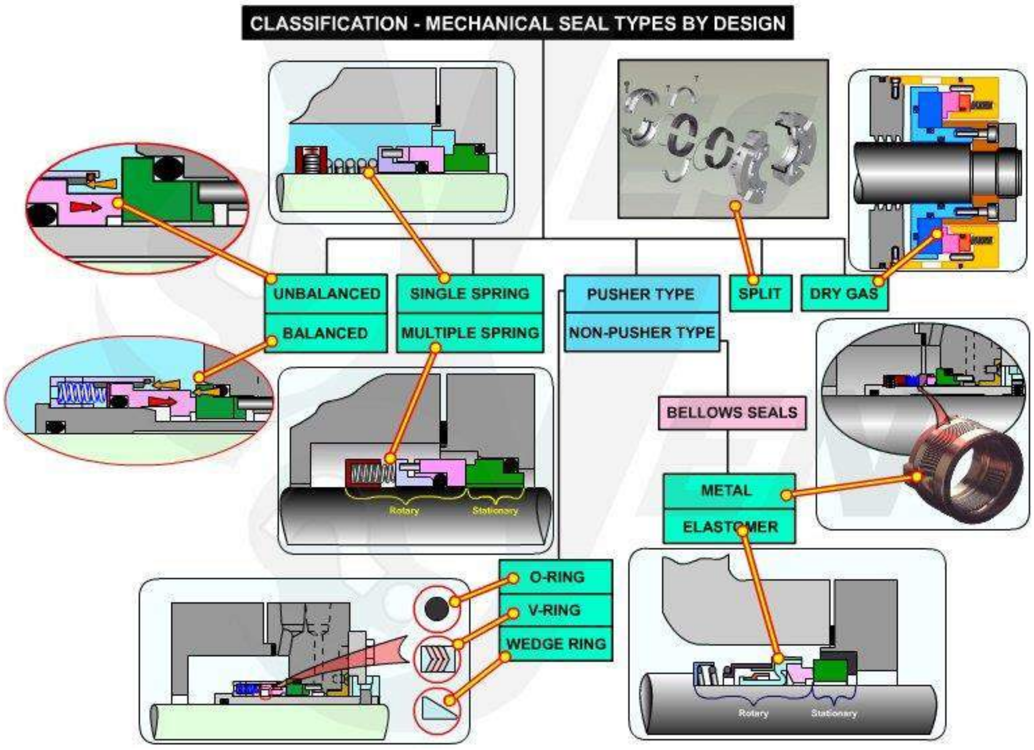


The seal is comprised of a rotating (yellow) and stationary (orange) face. The faces are flat within 11 millions of an inch. This creates the primary sealing point in the seal.

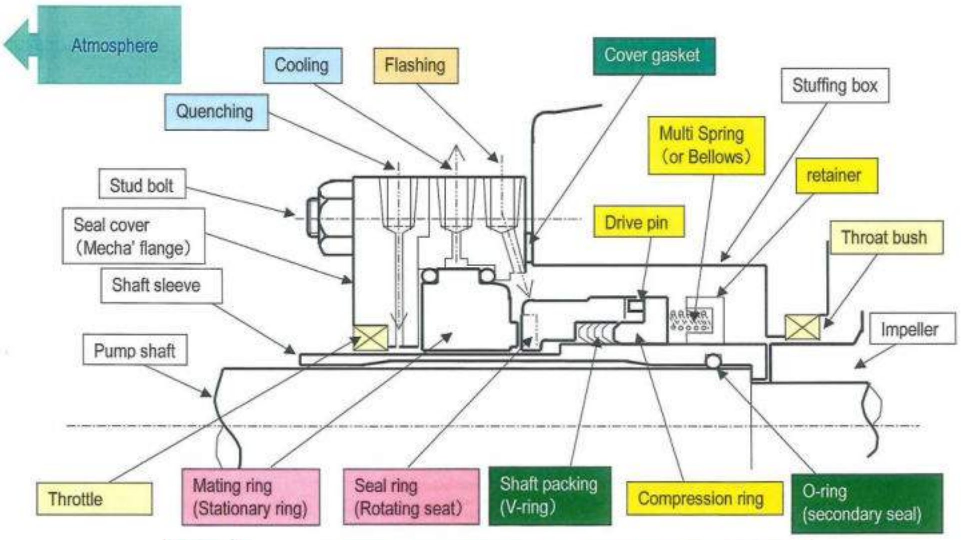
Process fluid provides lubrication for the seal faces.

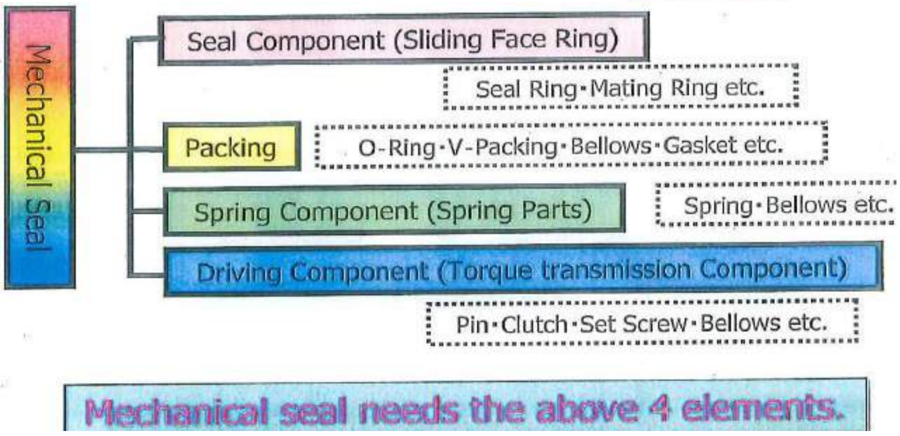
Closing forces (spring pressure +process pressure) keep the seal faces together.

Small amount of opening force allows process liquid to migrate between the seal faces. This liquid is critical to seal performance. It provides cooling and lubrication.

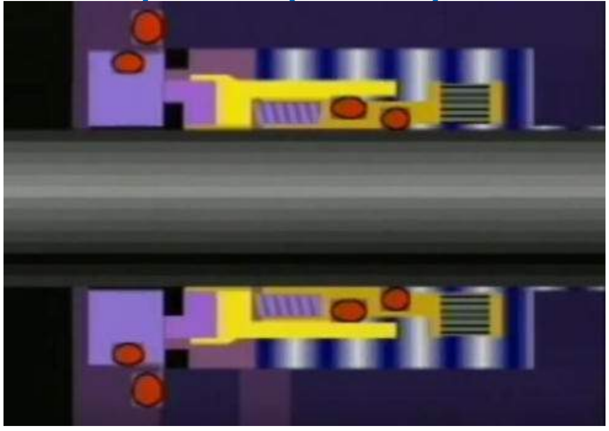

CLASSIFICATION - MECHANICAL SEAL TYPES BY DESIGN
UNBALANCED
BALANCED
SINGLE SPRING
MULTIPLE SPRING
PUSHER TYPE
NON-PUSHER TYPE
SPLIT
DRY GAS
BELLOWS SEALS
METAL
ELASTOMER
O-RING
V-RING
WEDGE RING
Rotary
Stationary
Rotary
Stationary

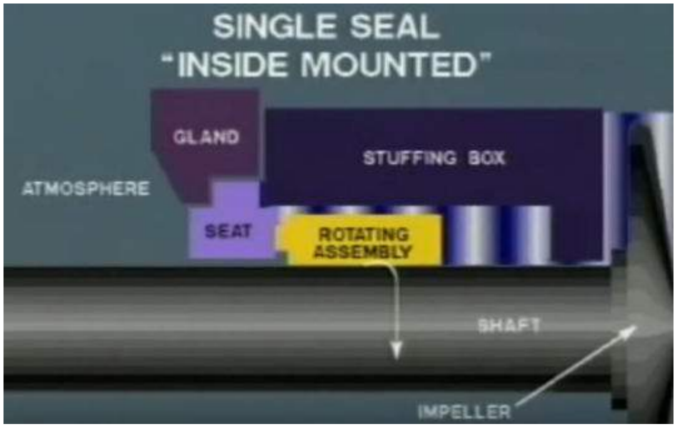
**MECH. SEAL PARTS:**

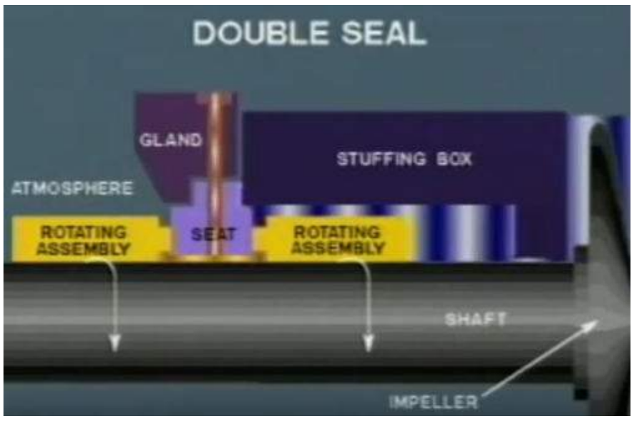

Atmosphere
Cooling
Flashing
Cover gasket
Stuffing box
Quenching
Multi Spring (or Bellows)
retainer
Stud bolt
Seal cover (Mecha' flange)
Drive pin
Throat bush
Shaft sleeve
Impeller
Pump shaft
Throttle
Mating ring (Stationary ring)
Seal ring (Rotating seat)
Shaft packing (V-ring)
Compression ring
O-ring (secondary seal)

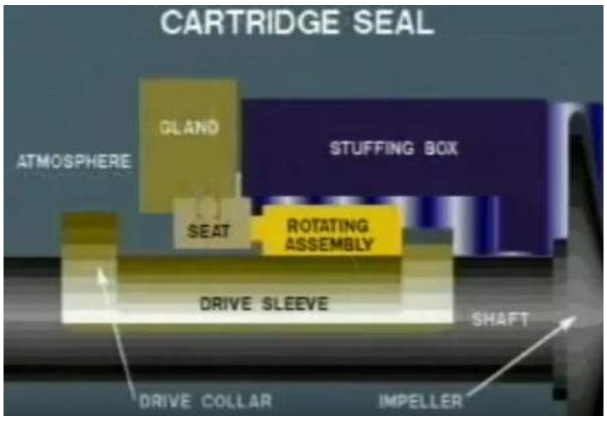

Mechanical Seal
Seal Component (Sliding Face Ring)
Seal Ring・Mating Ring etc.
Packing
O-Ring・V-Packing・Bellows・Gasket etc.
Spring Component (Spring Parts)
Spring・Bellows etc.
Driving Component (Torque transmission Component)
Pin・Clutch・Set Screw・Bellows etc.
Mechanical seal needs the above 4 elements.

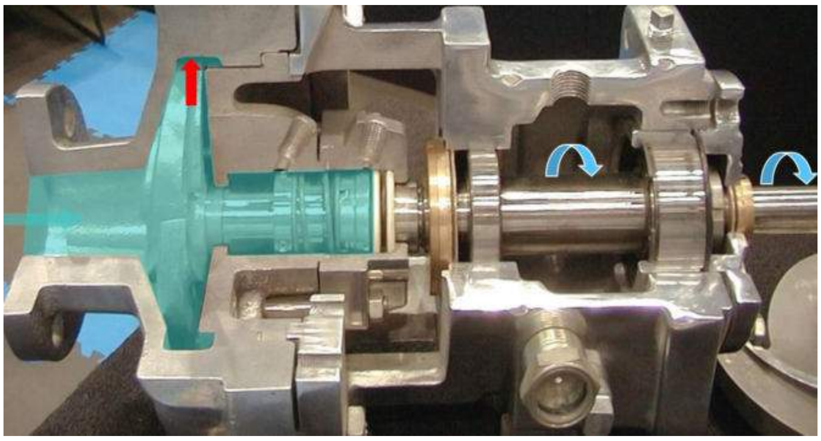
**Pumping Liquid flow from back side impeller to mechanical seal face /rotary face , stationary side fix (Atm.side) while rotating assly rotate with shaft (impeller side).**

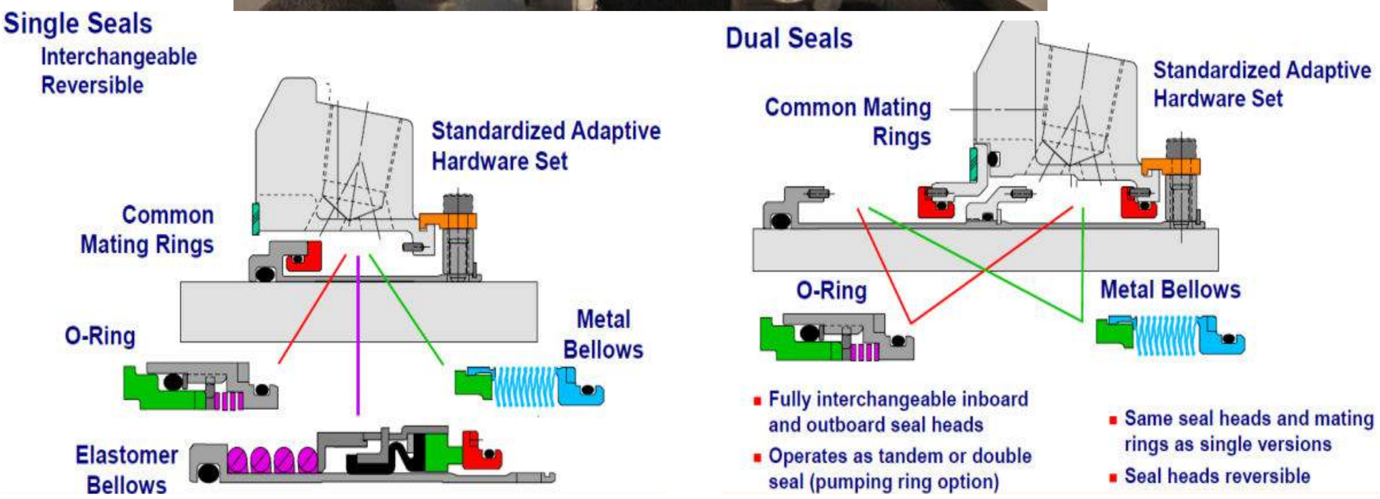



SINGLE SEAL
"INSIDE MOUNTED"
GLAND
STUFFING BOX
ATMOSPHERE
SEAT
ROTATING ASSEMBLY
SHAFT
IMPELLER

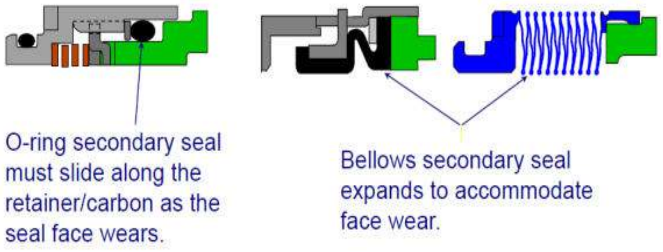

DOUBLE SEAL
GLAND
STUFFING BOX
ATMOSPHERE
ROTATING ASSEMBLY
SEAT
ROTATING ASSEMBLY
SHAFT
IMPELLER


CARTRIDGE SEAL
GLAND
STUFFING BOX
ATMOSPHERE
SEAT
ROTATING ASSEMBLY
DRIVE SLEEVE
SHAFT
DRIVE COLLAR
IMPELLER




Single Seals
Interchangeable
Reversible
Standardized Adaptive Hardware Set
Common Mating Rings
O-Ring
Metal Bellows
Elastomer Bellows
Dual Seals
Common Mating Rings
Standardized Adaptive Hardware Set
O-Ring
Metal Bellows

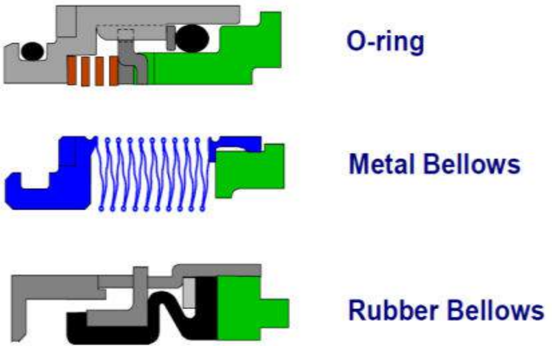
- Fully interchangeable inboard and outboard seal heads
- Operates as tandem or double seal (pumping ring option)
- Same seal heads and mating rings as single versions
- Seal heads reversible



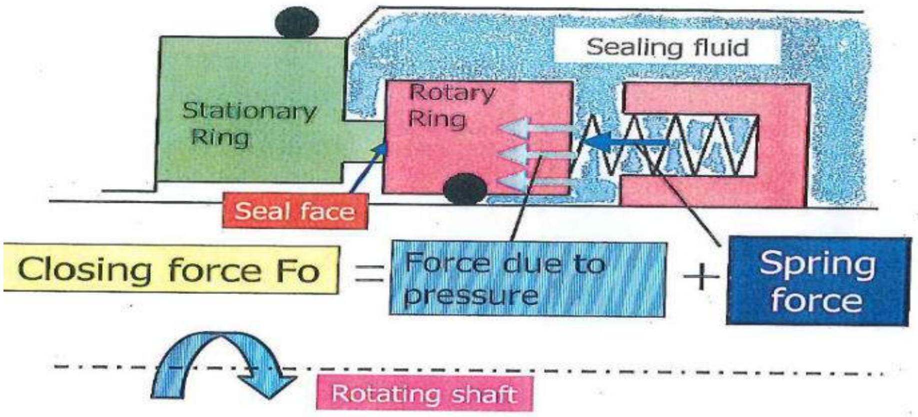
O-ring secondary seal must slide along the retainer/carbon as the seal face wears.

Bellows secondary seal expands to accommodate face wear.

**Pusher** vs. **Non-Pusher**


O-ring
Metal Bellows
Rubber Bellows

## MECHANISM OF MECH.SEAL


Sealing fluid
Stationary Ring
Rotary Ring
Seal face
Closing force Fo
=
Force due to pressure
+
Spring force
Rotating shaft

**Mechanical seals are rapidly replacing the gland packing because following disadvantages.**

1. Atmospheric pollution due to persistent leakage.
2. Loss of pumpage due to persistent leakage.
3. Frequent maintenance due to wearing out of the shaft sleeve and deterioration of the packing over the period of time.
4. Excessive power consumption due to continuous friction of the pump shaft with the shaft sleeve.
5. Chances of overheating and fuming due to excessive tightening.

**Mechanical seals became widely popular because of their remarkable advantages over the Packing such as:**

1. Minimum atmospheric pollution because of negligible leakage or no leakage at all.
2. Wastage of time because of repacking of stuffing box is saved considerably.
3. Better sealing capacity and longer operational life.
4. Low maintenance cost because of minimum failure rate.
5. Remarkable reduction in power consumption, hence more effective and economical.

## BASIC CONSTRUCTION OF A MECHANICAL SEAL:

- Basically the mechanical seal consists of a rotating seal ring and a stationary seal.
- The rotating seal ring continuously rotates with the shaft or shaft sleeve against its stationary counterpart as long as the pump is in operation.
- The rotating seal ring is kept pressed by a single spring or by a set of spring against the stationary seat at all times during operation.
- Many types of secondary seals are used to seal the rotating seal ring on the shaft or shaft sleeve. The two most common secondary seals are PTFE wedge and o-ring.

## Mechanical seal Basic operating principle :

Rotating seal ring and stationary seat are the primary sealing members of the mechanical seal.
" PTFE wedges, PTFE gaskets, Rubber o-rings etc. form the secondary sealing members.
The faces of primary seal members are extremely flat and lapped to the highest degree of accuracy to such an extent that it is extremely difficult for the liquid to escape through them to the atmosphere.
However there always exists a thin film of the pumped liquid that separates cools and lubricates the seal faces. The nature of this film is such that when the liquid approaches the atmospheric end, it vaporizes and no leak is virtually observed.

**Why Mechanical Seals Fail--**

**Mechanical Seals failures seem to fall into four broad categories:** **1 )**The seal motion was restricted and the faces opened 2 ) Heat caused the 0-rings to deteriorate. **3 )**The seal materials were attacked by the fluid sealed. **4 )** The seal was installed incorrectly.

**Mechanical Seals motion restricted:** The spring-loaded (dynamic) seal face constantly moves to maintain full face contact with the stationary seal face. The main reasons for this movement are **1 )**The stationary face is not perpendicular to the pump shaft. 2 ) The pump has bearing end play. This means that the shaft moves back and forth a few thousandths of an inch at frequent but random intervals. **3 )** There is some impeller unbalance causing shaft whip. **4 )**The pump is operated away from its BEP, causing side loads on the shaft. **5 )** There is thermal shaft growth and Pump vibration that affects the seal.

**the major conditions that can restrict.. Movement of the spring loaded mechanical seals face:** **1 )**Solids have collected in the seal or around the dynamic seal ring. **2 )**The fluid sealed has caused the dynamic 0-ring to swell. **3 )** The temperature limit of the dynamic 0-ring has been exceeded and the 0-ring has lost its elasticity (compression set) or become hard. **4 )** Spring compression is inadequate because of incorrect installation. **5 )** Solids in the stuffing box, gasket protrusion or other foreign material restrict the motion of the dynamic seal ring.

**Thermal degradation of Mechanical Seal 0-rings:** 0-rings are the one part of a mechanical seal that are sensitive to heat because of the way they are manufactured. The ingredients are mixed together, put in a mold and cured at high temperature for a specific time. The compound will then assume the shape of the mold and its hardness, or durometer, will increase. When the 0-ring is placed in an 0-ring groove in a seal and heated to a temperature beyond its recommended limit, the curing process will continue and the 0-ring will take a compression set. This means that the 0-ring has lost some of its resilience and squeeze, and fluid may leak past the 0-ring. The higher the temperature, the shorter the time before the 0-ring takes a compression set. When an 0-ring is exposed to high temperature for a long period, it will become hard and brittle, causing mechanical seals failure.

**Mechanical seals installed incorrectly:** Many mechanical seals fail at initial start-up or prematurely because they were not installed correctly. Cartridge seals eliminate all measurement, protect the seal faces from contamination and are easy to install. With these seals, installation problems are minimized. The Outside seal is preset and requires no installation measurement. Only in-line seals require careful measurement to insure correct installation. By following the mechanical seals installation instructions, step-by-step correct seal installation is easily achieved.

## Mechanical Seals - Face Materials

**Ceramic** - Generally a 99.5% aluminum oxide offering excellent wear characteristics due to its hardness. It is chemically inert and can be applied to nearly any product. Ceramic cannot however handle the thermal shocks that Ni-resist or 17-4 seats can. They will also shatter like a plate if dropped on concrete.

**Silicon Carbide** - Is a bluish-black material created by fusing silica and coke. It is in the same family as Ceramic (due to the Silica), but has much better lubrication qualities and is harder. The most common is reaction-bonded silicon carbide. In Chemical applications however, Alpha Sintered Silicon Carbide may be recommended. Alpha Sintered Silicon carbide does however sacrifice the Pressure Velocity ratios due to the lack of un-reacted free carbon. Either grade of SIC can usually be re-lapped and polished to be reused.

**Tungsten Carbide** - A very versatile seal face like Silicon Carbide. It is very hard like silicon carbide however it is very heavy to the touch, making it easy to distinguish from silicon carbide. Ideal for high pressure applications due to a high modulus of elasticity which helps prevent face distortion. Tungsten carbide also can be re-lapped and polished to be re-used.

**Ni-resist** - Is a form of Stainless steel which has had nickel added to it to lower the friction generated by the rotating face. it is an inexpensive seal face and ideal for fresh water applications.

**GFPTFE** - Say that one ten times.... Glass Filled PTFE (most people just say Teflon (R)). Gives the chemical resistance of PTFE however glass must be added to give the face hardness and to prevent cold flow issues associated with PTFE.

**Carbon** - Is the most often used seal face. Carbon has excellent anti-frictional qualities and is compatible with an extremely wide range of temperatures and corrosive environments. It is not however good in abrasive applications. Resin-impregnated carbon graphite-The best seal grades are machined to near final shape, then baked to improve physical properties. The final resin impregnation is only used to make the carbon gas-tight, and only penetrates the surface of the part. “Machinable” grades often used by seal repair shops are manufactured to be porous throughout so that the resin impregnation penetrates the entire part. This allows a carbon part to be machined from tube stock. These grades wear rapidly and run poorly. Carbon is not acceptable in the presence of a strong oxidizing agent. Carbon graphite running against Silicon carbide has a low coefficient of friction, and is the best choice for most applications. Silicon carbide is the hardest of all seal face materials

**Elastomers (0-Rings):**

**Fluorocarbon (Viton or Fluorel) - 75** durometer is preferred. Avoid colored (brown or green) grades; the clay fillers used to replace carbon black are subject to chemical attack. - 15F to +400 F

**Ethylene Propylene (EP, EPR, EPDM)** - Peroxide cured grades are preferred. -65 F to +300 F

**Neoprene** - Excellent for sealing refrigeration fluids such as Freon ®. -65 F to +250 F

**Aflas -** Preferred for combinations of oil and amines or ammonia: sour crude oil, sour gas, refrigeration. -20 F to +400 F (excursions to +600)

**Perfluoroelastomer (Kalrez, Chemraz)** - Supplied for some chemical and high temperature applications. Kalrez compound 4079 is most common, and offers improved compression set resistance over compound 1050 , When selecting an 0-ring compound, be sure to consider not only the main fluid pumped but also the minor constituents of the pumpage and any fluid used periodically to clean out the system.

## Mechanical Seal Repair / Can the seal be rebuilt?

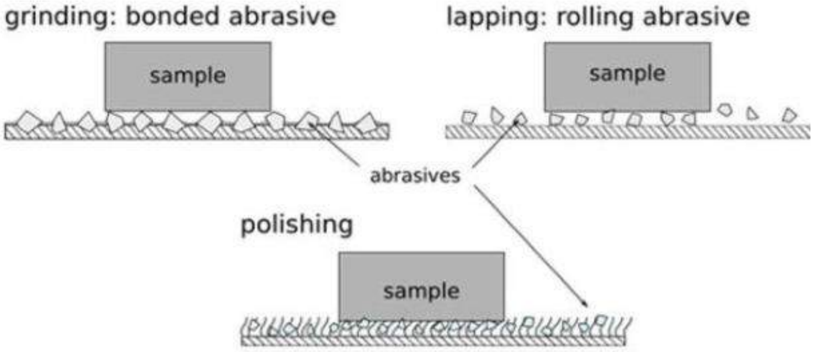
Obvious but in some seals catastrophic damage to the seal such as a broken sleeve or an extremely eroded gland would indicate that you may have significant problems that would prevent a repair. All mechanical seals function basically the same way. Two mating faces contact each other forming a seal at the mating surface. Usually one surface is made of a soft material such as carbon and the other surface is made from a hard material such as silicon carbide. A series of O-rings or other sealing materials form seals on the shaft and gland area. Everything is held in the stuffing box by a gland of some sort. Depending on the design of the mechanical seal, everything may be mounted on a sleeve and cartridge mounted to incorporate the gland into the seal itself.

**FACE FLATNESS**: The mechanical seal faces are obviously the most critical sealing point of a mechanical seal assembly.

- Although the faces can be manufactured from a variety of different materials, one is typically carbon, while the other is usually a hard material. (i.e. Alox (Aluminum Oxide Ceramic), Tungsten Carbide, Silicon Carbide, etc.)
- In order for a “seal” to be achieved, the faces must be very flat. This is achieved by machining the faces, then “lapping” them to a fine finish.
- **Flatness is measured in “Light Bands”**. After lapping, the faces are placed on an “Optical Flat”, a clear glass surface where a monochromatic light is shined on the face. This single wavelength light will produce an image of rings or lines on the face. Each ring/line is “One Light Band”. Each light band is equivalent to .000011” or

eleven millionths of an inch. This refers to the variations in the surface of the face. On most face materials, one to three light bands is LE-CON's standard.

- **LAPPING AND SURFACE FLATNESS : GRINDING > LAPPING > POLISHING**


grinding: bonded abrasive
lapping: rolling abrasive
sample
sample
abrasives
polishing
sample

LAPPING & POLISHING CONSUMABLES / GRINDING WHEEL
Diamond Powder
Daimond Paste
Lapping Abrasive
Lapping Oil
Valve Grinding Paste
Diamond Slurry
Polishing Pad
Polishind Pad
Felt Pad
Diamond Wheel

- Surface flatness is measured in terms of light bands with the help of monochromatic light and optical flat
- **1 light band = 11.6 million of an inch in one inch length =0.00029 mm in one inch length**

✓ If light band straight – surface is flat
✓ If the line curve towards the point of contact –surface is concave
✓ If the line curve away the point of contact –surface is convax

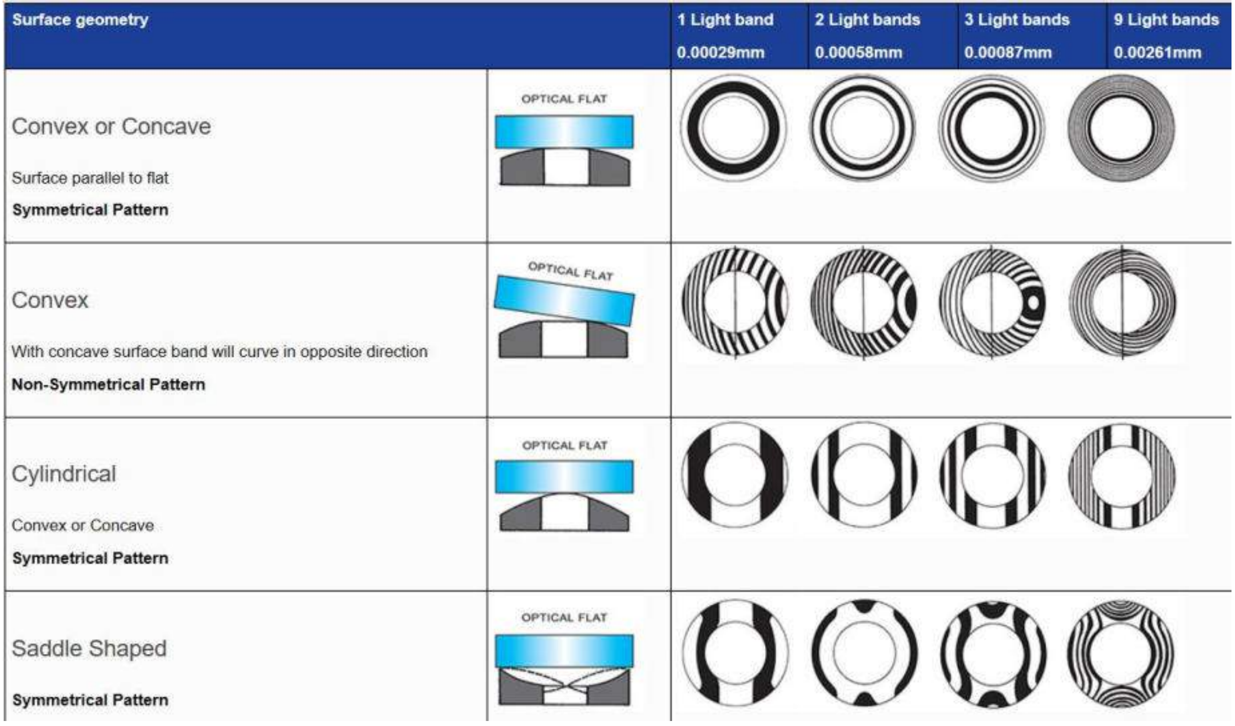
**What are light bands?**

Light Bands were discovered by Isaac Newton who first studied them in 1717. They are an interference pattern created by the reflection of light between two surfaces.

When using a monochromatic light source it is possible to use the phenomenon to calculate the flatness of a component, but the surface of the component must be reflective in order for the light bands to appear. The light bands are made up of a bright and dark fringe. Combined, these correspond to the wavelength of the monochromatic light which in the case of a Sodium light source is equal to 589nm. When checking parts for flatness, it is only the dark bands that are counted, so as this is half the total fringe, each dark band equals 294nm or 0.00029mm.

Diamond lapping processes are ideal for producing reflective surfaces, which can be measured for flatness using this method directly after the lapping operation.

**Typical light band patterns which show flatness accuracy**



| Surface geometry | | 1 Light band<br>0.00029mm | 2 Light bands<br>0.00058mm | 3 Light bands<br>0.00087mm | 9 Light bands<br>0.00261mm |
|---|---|---|---|---|---|
| Convex or Concave<br>Surface parallel to flat<br>**Symmetrical Pattern** | OPTICAL FLAT | | | | |
| Convex<br>With concave surface band will curve in opposite direction<br>**Non-Symmetrical Pattern** | OPTICAL FLAT | | | | |
| Cylindrical<br>Convex or Concave<br>**Symmetrical Pattern** | OPTICAL FLAT | | | | |
| Saddle Shaped<br>**Symmetrical Pattern** | OPTICAL FLAT | | | | |

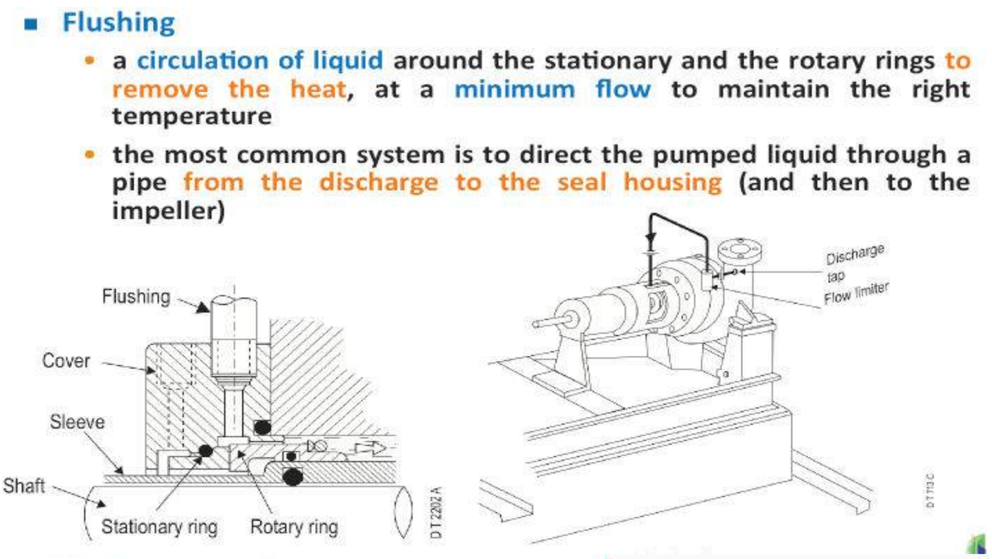
## Thumb rules for mechanical seals:

**Before selecting your mechanical seal design there are three things you want to remember:**

- All of the seal materials must be chemically compatible with any fluids that will be pumped through the system and that includes solvents, cleaners or steam that might be introduced into the system to flush or clean the lines. It also includes any barrier fluids that are used to circulate between dual mechanical seals.
- The seal faces must stay together. If they open, the seal will leak and allow solids to penetrate between the faces. The solids will eventually destroy the lapped surfaces.
- **Good seal life is defined as running the mechanical seal until the carbon face is worn away**. Any other condition is called a seal failure and is always correctable.

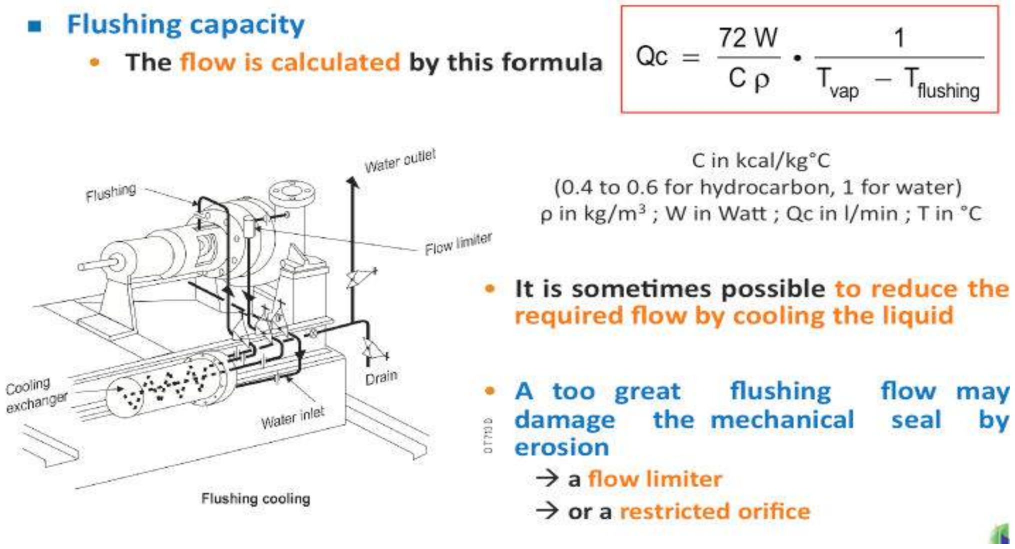
**The term "flushing" to describe six different methods of bringing fluid to the stuffing box area of a centrifugal pump.**

- Discharge recirculation
- Suction recirculation
- Flushing
- Barrier or buffer fluid
- Jacketing fluid
- Quenching



**Flushing**

- a circulation of liquid around the stationary and the rotary rings to remove the heat, at a minimum flow to maintain the right temperature
- the most common system is to direct the pumped liquid through a pipe from the discharge to the seal housing (and then to the impeller)



**Flushing capacity**

- The flow is calculated by this formula

$$Q_c = \frac{72\ W}{C\ \rho} \cdot \frac{1}{T_{vap} - T_{flushing}}$$

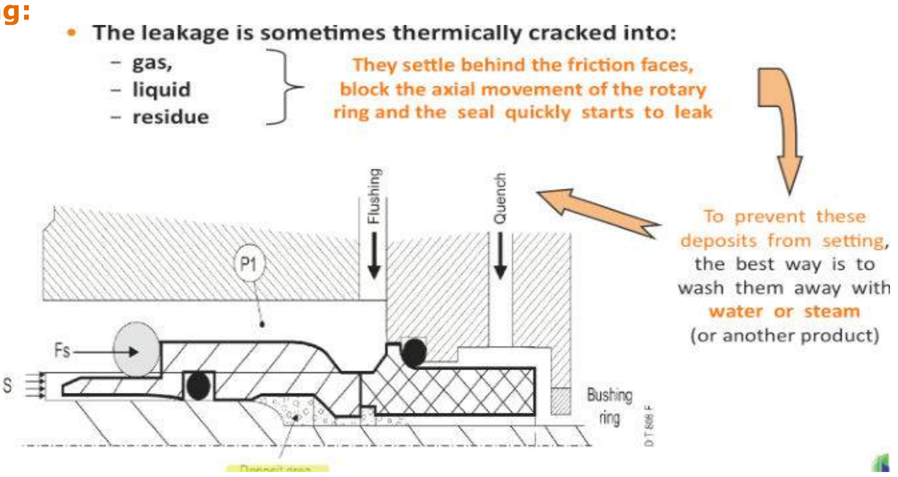
C in kcal/kg°C
(0.4 to 0.6 for hydrocarbon, 1 for water)
ρ in kg/m³ ; W in Watt ; Qc in l/min ; T in °C

- It is sometimes possible to reduce the required flow by cooling the liquid
- A too great flushing flow may damage the mechanical seal by erosion
  - → a flow limiter
  - → or a restricted orifice

Flushing cooling

- A process fluid or clean liquid from an outside source is brought into the stuffing box through a regulating valve or orifice at pressure 1 bar higher than the stuffing box pressure. The liquid should be brought in at the bottom of the stuffing box to ensure thorough cleaning. All this liquid will go into the product.
- Seals usually require 30 to 60 liters to flush per hour depending on the seal size or process requirements.
- Flushing may be the process liquid or compatible liquid to the process fluid.
- Flushing serves the following purposes:
  - To cool the seal faces.
  - To lubricate the seal faces.
  - To make a thin stable film of the liquid between the seal faces.
  - To remove the solid particles between the seal faces.

## Quenching:



- The leakage is sometimes thermically cracked into:
  - gas,
  - liquid
  - residue

They settle behind the friction faces, block the axial movement of the rotary ring and the seal quickly starts to leak

To prevent these deposits from setting, the best way is to wash them away with water or steam (or another product)

Flushing
Quench
P1
Fs
S
Bushing ring
DT 808 F

- ➢ Quenching media may be different from the process fluid to be given at the atmospheric side on low pressure side of the seal. **Quench in a seal plan is a low pressure blanket over the atmospheric side of the mechanical seal.**
- ➢ Fluid is introduced outside the mechanical seal between main seal and throttle bushing at pressure around 3 psi.
- ➢ It may be –nitrogen (0.5kg/hour), steam (0.5kg/hour) or water (1-2 liters / hour).
- ➢ It serves the following purposes:
- ○ Smoothening: If the process fluids reacts with oxygen and create a hazardous or toxic material, Nitrogen is given.
- ○ Heating: If the process fluid cools at the low pressure side may solidify and interface the film. Therefore heating is necessary. E. g .tar handling pump.
- ○ Crystallization: Some liquids have the tendency to crystallize when they come in contact with the atmosphere. Quenching can prevent the crystallization.

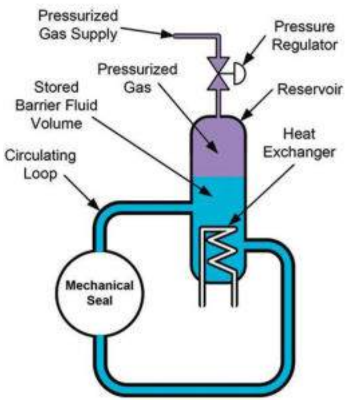
Drawback: Since the steam is a popular medium for quenching, there is a danger of steam to penetrate through the oil seals of the bearing housing that can contaminate the lubricating oil.

## Barrier / buffer fluid:

- ➢ **Barrier or buffer fluid provides an environment between two seal faces**. Over a certain period of operation, it contaminates with the process fluid or breaks down under high temperature and need to replace by the fresh one.
- ➢ **Barrier fluid:**

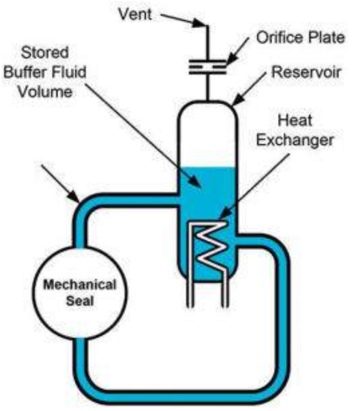
  When the pressure of the fluid between the seals is higher than the seal chamber pressure, then the fluid is called barrier fluid. It utilizes externally supplied liquid which can either be liquid or gas.
- ➢ **Buffer fluid:**

  **Buffer means a cushion-like device that reduces or absorbs shocks due to impact**. When the pressure of the fluid between the seals is lower than the seal chamber pressure, then the fluid is called buffer fluid.



Pressurized Gas Supply
Pressure Regulator
Pressurized Gas
Stored Barrier Fluid Volume
Reservoir
Heat Exchanger
Circulating Loop
Mechanical Seal

Barrier system

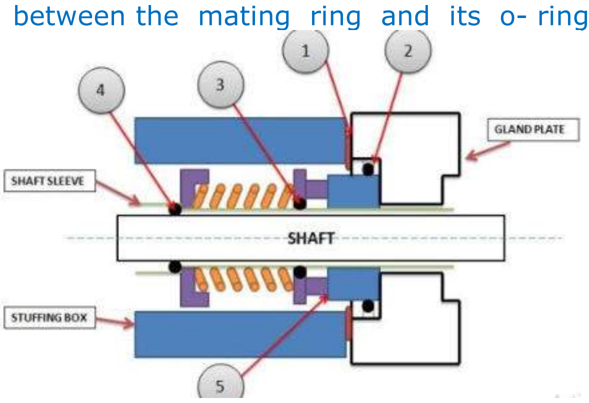


Vent
Orifice Plate
Stored Buffer Fluid Volume
Reservoir
Heat Exchanger
Mechanical Seal

Buffer system

**5 paths of seal leakage:**

- Leakage between the pump shaft and the shaft sleeve (4).
- Leakage between the Rotating face and its secondary seal (5).
- Leakage between the Rotating face and stationary seat(3)
- Leakage between the seal chamber and gland gasket (1).
- Leakage between the mating ring and its o- ring/gasket(2)



1
2
3
4
5
GLAND PLATE
SHAFT SLEEVE
SHAFT
STUFFING BOX

**At the gland gasket.** This is the easiest leak to detect because it's very visible and does not change with shaft rotation.

**Between the shaft sleeve and the shaft.** This is a common problem with double ended pumps, where the sleeve is used to position the impeller and there is no method of sealing the sleeve against the impeller.

**Between the seal face and its metal holder.** The leakage frequently increases, as the product temperature increases, because the metal face holder has an expansion rate three times that of the carbon face.

**Through fretting damage** The damage is caused by spring loaded dynamic o-rings, Teflon wedges, chevrons, U- cups etc. **&** can't miss the fret marks. , located on the pump shaft, pump sleeve, or inner sleeve of the mechanical seal.

**Mechanical seal plan** : **@30 types of seal plan (API 610 / 682 )**

- ✓ **SINGLE SEAL PLANS** –01,02,11,13,14,21,23,31,32 & 41 (10 plan)
- ✓ **DUAL SEAL PLANS** - 52,53A,53B,53C & 54 (05 plan)
- ✓ **QUENCH SEAL PLANS** - 62
- ✓ **GAS SEAL PLANS** – 72,74,75,76

**Mechanical seals fail for only two reasons:**

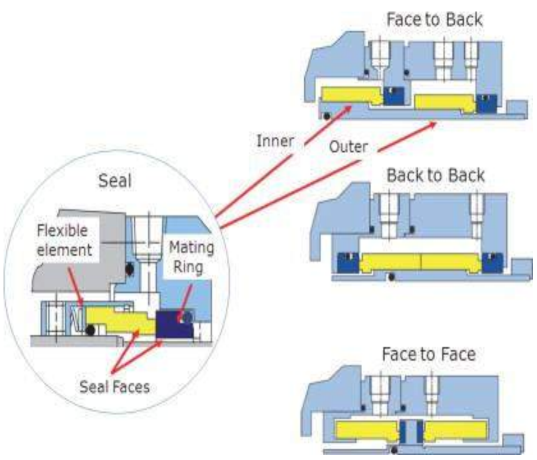
- **One of the seal components becomes damaged & the lapped faces open.** Common sense dictates that the more the shaft deflects from the center of the stuffing box, the more likely the lapped faces are to separate. Rotating seals (the spring loaded face rotates with the shaft) are very sensitive to this type of shaft displacement or any other form of misalignment between the Stationary and rotating faces.

**What is involved in a normal seal repair?** Let's take a close look at a typical sequence:

1. Inspect and troubleshoot the various components for evidence of corrosion, rubbing, wear or damage. This type of failure analysis should be a normal part of repairing seals.
2. Disassemble the seal and throw away the following components:
   - The carbon/graphite face.
   - The elastomers and gaskets.
   - The spring or springs.
   - The set screws
   - Any drive lugs or anti-rotation pins.
   - Cracked or broken hard faces.
   - Cracked or broken bellows.
3. Clean the remaining components such as the sleeve, face holder, adapter, etc.
4. Inspect the cleaned components to be sure they meet the manufacturer's original dimensions, tolerances, and finish.
5. Some metal-carbon composites have to be stress relieved after assembly to remove manufactured stress that will prevent the carbon from remaining flat during the storage and shipment period. Watch out for seals that are used in cryogenic service. They should be lapped at their cryogenic operating temperature. If you intend to insert a carbon into a metal holder, you will be better off pushing it in with an arbor press. If you try to expand the holder and shrink it to the carbon you'll have problems maintaining face flatness unless you stress relieve the assembly.
6. Reassemble the components using only new parts that have been supplied by the manufacturer. Be sure to use original equipment parts because many seal manufacturers design components that have been created from "finite element analysis" or similar techniques. Solid hard faces can be relapped if they are not damaged in any way. Plated or coated faces must be stripped and re-plated before lapping.
7. Check the assembled seal for flatness. A vacuum check should be performed on the movable assembly to insure there is no leak path through or around any of the components. If you elect to check cartridge mounted double seals with an air test, avoid immersing the seal in water. If the seal was later installed in hot oil, or a similar application, the water trapped in gaskets and small crevices would flash to steam generating possibly dangerous pressures.

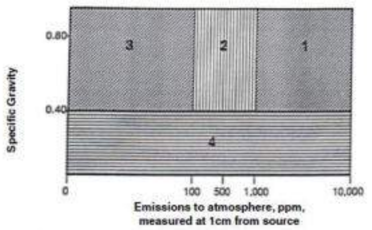
**Double Seal orientation**

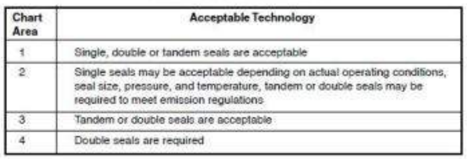
- a) Face-to-back (tandem): one mating ring is between the two flexible elements and one flexible element is between the two mating seal rings
- b) Back-to-back: both of the flexible elements are between the mating seal rings
- c) Face-to-face: both of the mating seal rings are between the flexible elements.



**Seal Selection Can Be Based on the Fluid's Specific Gravity and the Maximum Allowable VOC Emission Levels**

**Size:** < 6 in. (152 mm)
**Pressure:** < 600 psig (40 bar)
**Speed:** < 3,600 rpm



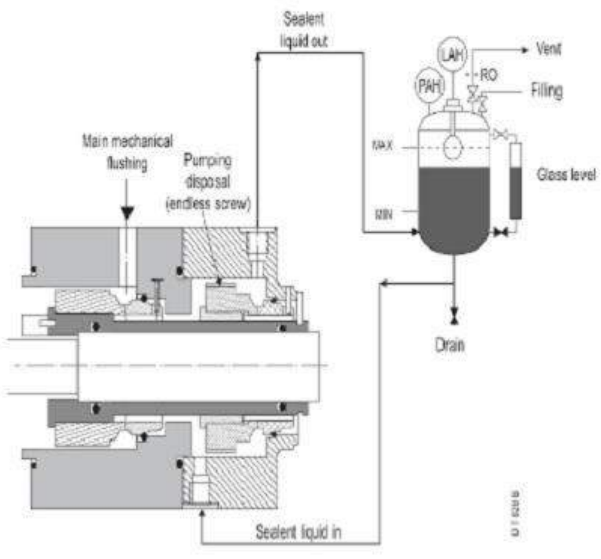


| Chart Area | Acceptable Technology |
|---|---|
| 1 | Single, double or tandem seals are acceptable |
| 2 | Single seals may be acceptable depending on actual operating conditions, seal size, pressure, and temperature, tandem or double seals may be required to meet emission regulations |
| 3 | Tandem or double seals are acceptable |
| 4 | Double seals are required |

## Double seal arrangement:

### TANDEM seal

- The 1st seal (inner seal) is a normal single seal with its flushing or dead-ended
- The 2nd seal (outer seal) is used to maintain a liquid barrier before the atmosphere
- No pressure in the tank. The liquid barrier circulation is ensured by an endless screw or fans (internal pumping ring)
- This is a suitable solution if the liquid is toxic, spontaneously ignitable, or vaporizable at atmospheric pressure (like LPG)



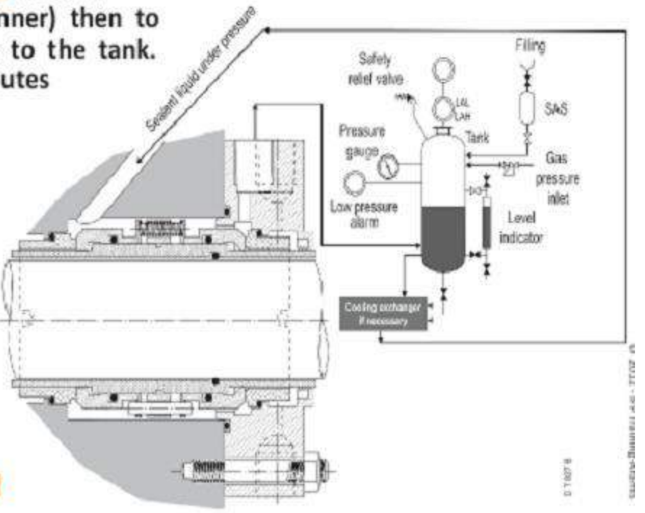
### BACK TO BACK seal arrangement

A liquid buffer is used as a:

- friction face coolant : it circulates from a tank to the most active seal (inner) then to the other seal before it returns to the tank. An internal pumping ring contributes to its circulation
- liquid barrier

The liquid buffer pressure is higher than the suction pressure: usually from 1 to 5 bars higher. It is given by a controlled pressure system provided by $N_2$

The liquid buffer can be oil, water, methanol, etc. It must be compatible with the pumped liquid because there is always a leakage through the friction faces.



- ➢ **Mechanical Seal selection basis**

**Mechanical seal selection shall consider the following item:**

a) Liquid: the metal parts must be corrosion resistant, usually steel, bronze, stainless steel, or Hastelloy. The mating faces must also resist corrosion and wear. Carbon, ceramic, silicon carbide or tungsten carbide may be considered. Stationary sealing members of Buna, EPR, FKM (Viton) and PTFE (Teflon) are common. Material shall also be checked to find the performance against the fluid. For example FKM (Viton) is not recommended for fluid contain H2S

b) Pressure: balanced or unbalanced, is based on the pressure on the seal and on the seal size.

c) Temperature: materials must be selected to handle liquid temperature.

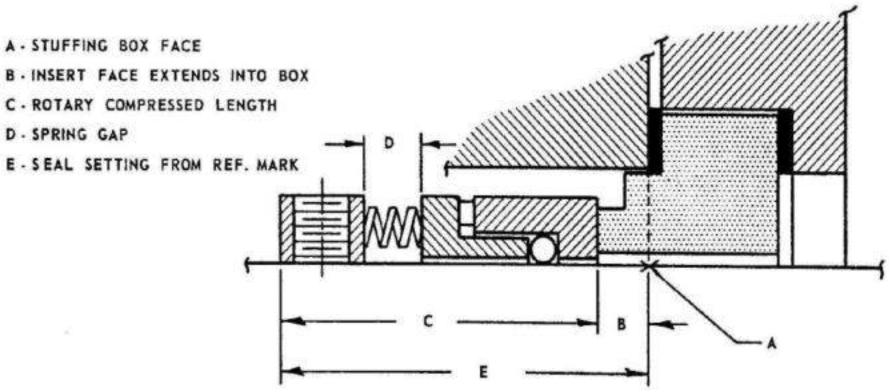
d) Characteristics of Liquid: abrasive liquids (like slurry) create excessive wear and short seal life. Flushing from an external source allows the use of mechanical seals. On light hydrocarbons balanced seals are often used for longer seal life even though pressures are low.

e) Reliability and Emission Concerns: seal type and arrangement selected must meet the desired reliability and emission standards where the pump will be applied. Dual seals (pressurized or un-pressurized) with buffer/barrier fluid could be a choice.

Detail selection is provided by API 682 as international standard for mechanical seal but purchaser shall also consult to seal vendor specialist to get proper seal selection.

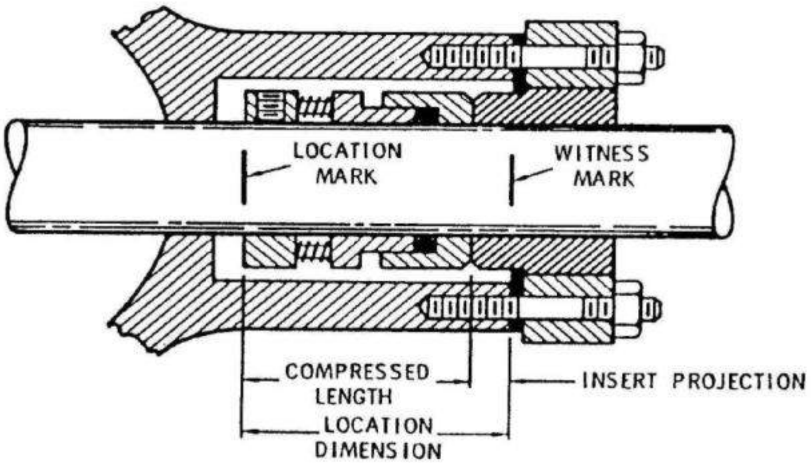
### INSTALLING THE SEAL

Before attempting to install a mechanical seal, be sure to look at the engineering seal drawing that comes with it. There are a number of dimensions shown on these drawings, but one of them is very important to the proper installation of the seal. On the drawing you will find a dimension that identifies the distance from the face of the stuffing box to the back edge of the locking collar on the rotating element. This is known as the location dimension. It will allow the locking collar to be positioned at a point on the shaft that will give the seal the proper compression when the gland ring is installed. The location dimension for the seal shown below is distance "E".


A - STUFFING BOX FACE
B - INSERT FACE EXTENDS INTO BOX
C - ROTARY COMPRESSED LENGTH
D - SPRING GAP
E - SEAL SETTING FROM REF. MARK
D
C
B
A
E

TYPICAL MULTIPLE SPRING SEAL DIMENSIONS

Once the location dimension has been determined and the shaft and stuffing box have been dressed, the following procedure should be followed to properly install the seal:
1) Scribe a reference mark (also called the witness mark) on the shaft that will line up with the stuffing box face.
2) Remove the shaft and scribe another mark, the location mark, on the shaft that is the same distance from the reference mark as the location dimension on the drawing.



WITNESS AND LOCATION MARKS ON THE SHAFT

3) Lubricate the shaft with a silicone lubricant (usually supplied with the seal.)
4) Mount the insert in the gland ring. Lightly lubricate the insert mounting O-ring and position it in the gland ring. Gently press the insert into the gland ring and seat it. Always try to avoid direct contact with the seal face. Make sure your hands are clean in case you do have to apply pressure directly to the seal face as you seat it.
5) If the seal is being installed from the impeller end of the shaft, slide the gland ring over the shaft and past the reference mark. Avoid bumping the insert against the shaft. If the seal is installed from the coupling end of the shaft, the gland ring will go on last.
6) Install the rotary unit parts on the shaft in the proper order. Lubricate the shaft packing O-ring and take care not to roll or pinch it as it slides into place. Again, try to avoid contact with the seal face.
7) Set the back of the locking collar on the location mark and tighten the set screws firmly and evenly.
8) Reassemble the pump, making sure to clean and flush the stuffing box.
9) Seat the gland ring and ring gasket to the stuffing box face by tightening the gland nuts/bolts evenly and firmly. Check manufacturer's specs for proper torque.

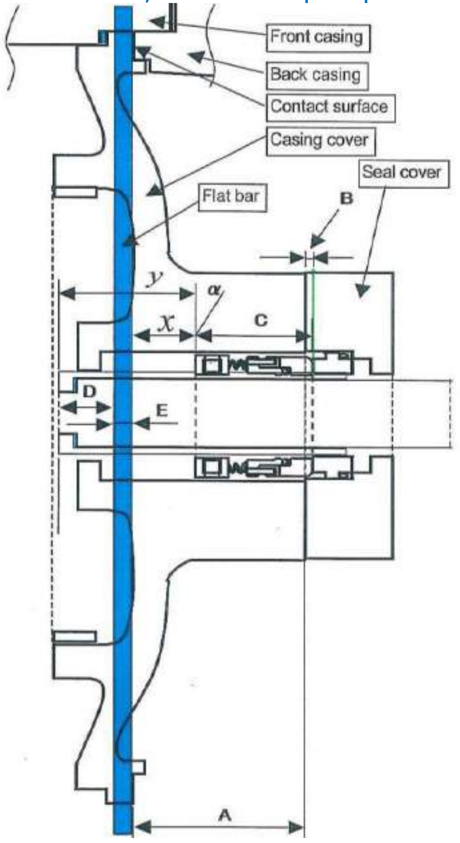
## STARTUP PROCEDURES

The following recommendations cover startup procedures for most mechanical seals:
A) **Never run a seal dry!** It probably won't hurt to bump the motor to check rotation, but running the seal dry for even a few seconds can seriously damage it.
B) Vent the stuffing box before starting the pump. Even if the pump has a flooded suction, air can still get trapped in the upper portion of the stuffing box. This is especially important in vertical installations.
C) New seals may leak somewhat during initial startup. Allow a reasonable amount of time (30-60 minutes should do it) for the seal faces to "wear-in" to each other.
D) Do not open the seal faces for inspection unless absolutely necessary. Seals establish a wear pattern which micro-scopically matches the two faces. When the insert is removed it cannot be put back together with any hope of matching the original wear pattern.
E) Outside seals on vertical turbine pumps can be set by raising and lowering the shaft with the adjusting nut on top of the motor. Raise the shaft the distance equal to the compression distance for the spring. Lock the rotating assembly on the shaft and then lower the shaft to compress the spring.

## Fitting Conventional Mechanical Seals

- Mark position of face of stuffing box on shaft
- Dismantle pump
- Lubricate tertiary seal

- Fit seat in end cover - ensure fully home and square
- Check seat is correctly located on anti-rotation pin
- Measure distance from front of end cover gasket to seat ('X') taking care not to scratch lapped face
- Look up seal working length in fitting instructions (L3)
- Add 'X' to L3 (or subtract depending on pump design) and note dimension ('Y')
- Measure 'Y' from mark on shaft towards impeller
- Mark shaft in this position
- Measure from this mark to end of shaft, or nearest step towards impeller and note dimension('Z')
- Carefully wipe lapped face of seat perfectly clean
- Place end cover on shaft taking care not to damage seat
- Lightly lubricate shaft and secondary seal
- Slide seal unit on to shaft, ensuring it is the right way round
- Wipe lapped face of seal perfectly clean, taking care not to damage the surface
- Fit seal 'Z' from end of shaft or shaft step, ensuring it is perfectly square to axis of shaft
- Evenly tighten grub screws
- Assemble pump taking care not to damage rotating seal unit
- Offer end cover to face of stuffing box. Check gap before compressing seal with 'A' dimension in fitting instructions
- If incorrect, dismantle pump and start again -If correct, tighten nuts on gland studs


Front casing
Back casing
Contact surface
Casing cover
Seal cover
Flat bar
B
y
α
x
C
D
E
A

※Data ②
< Set position >

1.Install the sleeve.
※The sleeve is temporary assembling.
※In the gasket use case of the sleeve...Do not forget set the gasket.

2.Apply a flat bar to the contact surface of the back casing.

3.Measuring "D".(Between "Sleeve end"and "Flat bar end")

4.Measuring "E".(Thickness of flat bar)

5.Find the value of "X".
※(x)=(A)+(B)-(C)

6.Find the value of "y".
※(y)=(D)+(E)+(x)

7.Set the seal ring on the sleeve.
Set position(y')=(y)+(α)
※"α" : Pushing value of the seal ring.

Find the value of "X".

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| x | = | A | + | B | - | C | | |
| ( ) | = | ( ) | + | ( ) | - | ( ) | | |

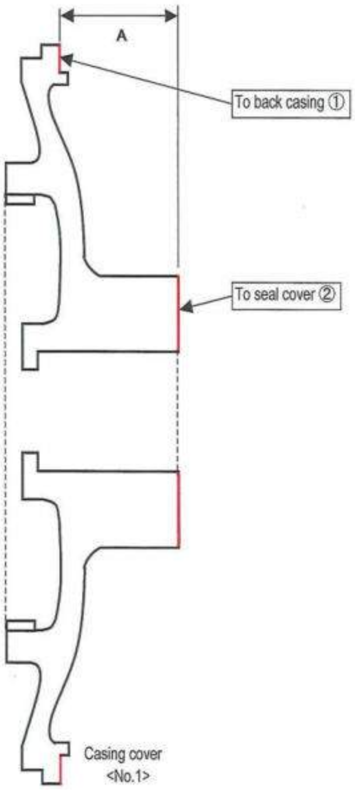
Find the value of "y".

| | | | | | | |
|---|---|---|---|---|---|---|
| y | = | D | + | E | + | x |
| ( ) | = | ( ) | + | ( ) | + | ( ) |

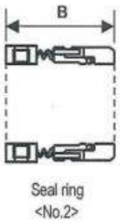
Set position" y' "

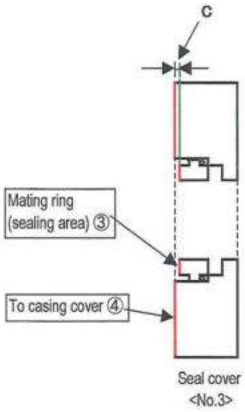
| | | | | |
|---|---|---|---|---|
| y' | = | y | + | α |
| ( ) | = | ( ) | + | ( ) |

※Data ①
< Measuring position >


A
To back casing ①
To seal cover ②
Casing cover
<No.1>

— : Contact surface




C
Mating ring
(sealing area) ③
To casing cover ④
Seal cover
<No.3>

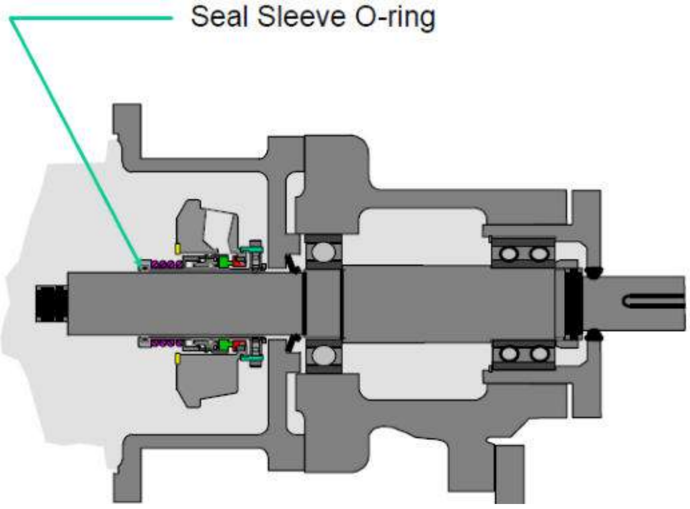
"A": Between ① and ②·······No.1

"B": Free length of seal ring.···No.2

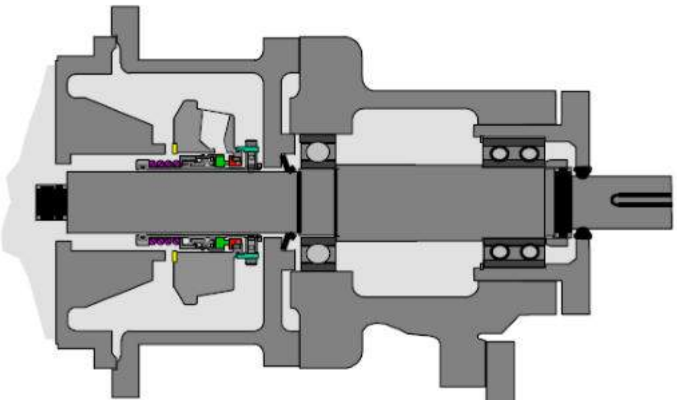
"C": Between ③ and ④·······No.3

## Cartridge Seal Installation procedure :

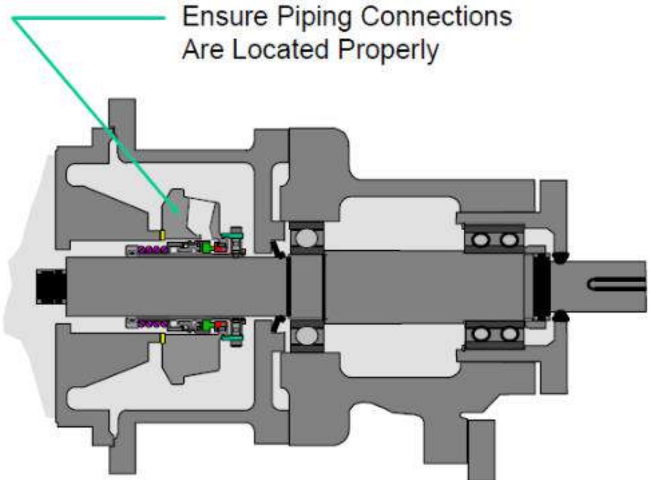
- Step 1 - Lubricate Sleeve O-ring & Slide On Shaft


Seal Sleeve O-ring

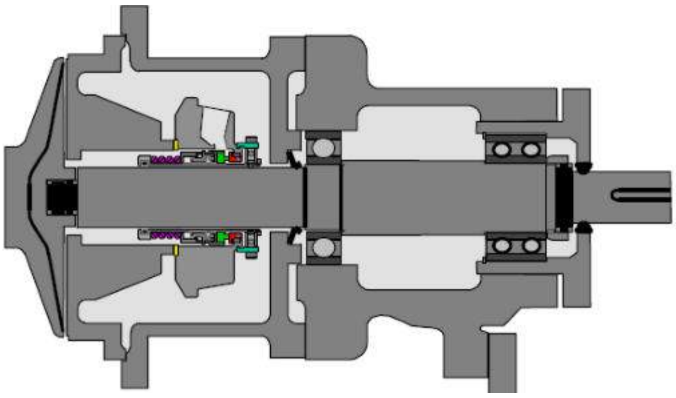
- Step 2 - Bolt Stuffing Box Cover to Frame



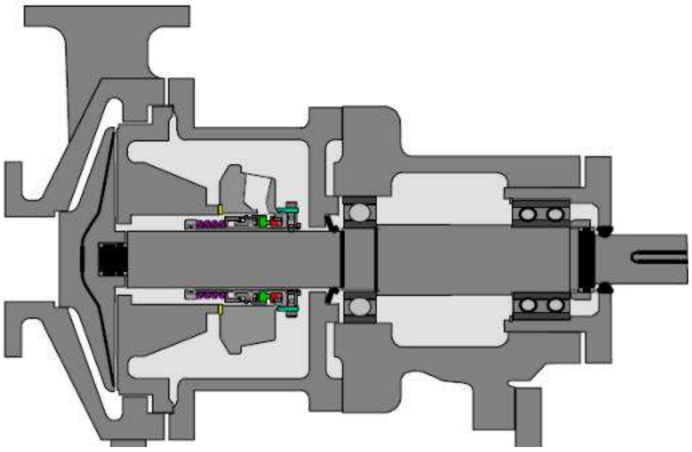
- Step 3 - Slide Seal to Stuffing Box & Bolt On


Ensure Piping Connections
Are Located Properly

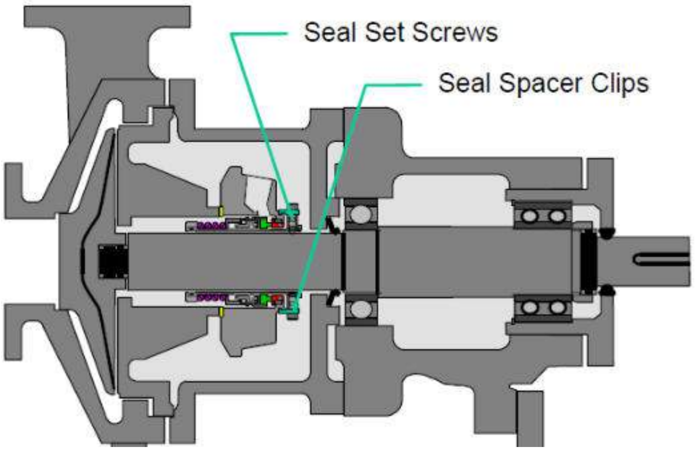
- Step 4 - Attach Impeller to Shaft



- Step 5 - Attach Pump Casing to Frame

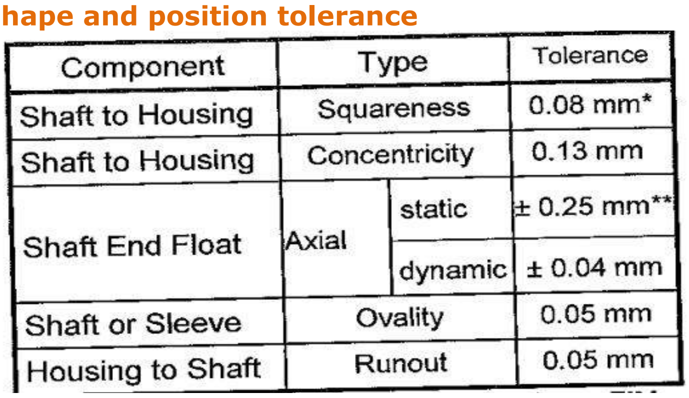


- Step 6A – Make final impeller adjustments



  - Step 6B – Check Seal Cartridge is Bolted to stuffing box
  - Step 6C – Tighten Seal Set Screws to Shaft
  - Step 6D – Remove Seal Spacer Clips

**Mechanical seal ---shape and position tolerance**



| Component | Type | | Tolerance |
|---|---|---|---|
| Shaft to Housing | Squareness | | 0.08 mm* |
| Shaft to Housing | Concentricity | | 0.13 mm |
| Shaft End Float | Axial | static | ± 0.25 mm** |
| | | dynamic | ± 0.04 mm |
| Shaft or Sleeve | Ovality | | 0.05 mm |
| Housing to Shaft | Runout | | 0.05 mm |

## MECH.SEAL HEAT GENERATION:

During operation, the seal faces are always kept apart by a thin film of liquid. The thickness of this film is obviously determined by the pressure gradient that is available in the seal chamber across the seal faces. In spite of this; a substantial amount of heat is generated across the seal faces. This heat must be controlled or minimized in order to achieve longer and better service by the seal.

The heat generated minimized by following way

- Size of the seal selected should be minimum possible.
- Seal chamber pressure should be minimum as far as possible. Preferably, low speed equipment’s should be used.
- Seal faces should possess minimum coefficient of friction.
- Face pressure of the seals should be minimum as far as possible. Seals should be hydraulically balanced.

Seals should be designed in such a way that frictional heat generated should be carried away to the maximum possible.

**In order to achieve optimum heat dissipation, following methods are employed in seal designed**

- Minimum 3 mm of diametrical clearance must be maintained between the rotating seal unit and the seal chamber bore.

- Face material of both the seals should have better heat conducting properties.
- Seal flushing liquid should be accurately directed at the mating surfaces of both the seals.
- Both the seal faces should be completely immersed in the media that is being sealed.
- Flushing and quenching must be employed wherever necessary.
- Seal chambers should be provided with cooling water jackets
- Seal size should be the smallest possible.
- In case of double mechanical seal, forced circulation of the barrier liquid should be implemented.

## WHY HYDRAULIC BALANCING?

In any mechanical seal, there are some closing forces and some opening forces that are always acting on the seal faces.

**The closing forces are-:**

- Mechanical force exerted by the spring/springs.
- Hydraulic force caused by seal chamber pressure.

**The opening forces are-:**

- Hydraulic force created across the seal faces by the pressure gradient
- Centrifugal force created by the action of the fluid that is thrown outward by the rotation of the pump shaft.

There is always a stable liquid film that exists between the seal faces. This film serves two basic purposes of cooling and lubrication. The absence of this film results in the faces rubbing against each other causing excessive overheating and wearing out of the seal. This liquid film has a pressure gradient varying from stuffing box pressure to the atmospheric pressure. Because of this film, a mechanical seal always leaks across the faces, but the leakage rate is so insignificant that it can be neglected.

When the stuffing box pressure increases beyond certain point, the hydraulic forces that hold the seal faces together increase to such an extent that the liquid film ruptures and the seal seizes to function. To avoid this, it is essential to balance the seal hydraulically, In other words, the liquids film between the faces produces a pressure gradient across the seal faces that tend to force the faces apart. However, it exerts lesser force than the opposing stuffing box pressure. The result is that there exists an unbalance hydraulic force push the sealing faces together. The greater the seal housing pressure, the greater is this unbalanced force. The face pressure eventually reaches the point where the liquid film no longer exists & seal runs without lubrication. To reduce this excess pressure, the hydraulic balancing is required.

PRESSURE GRADIENT: In a mechanical seal, rotating seal is always held pressed against the stationary seat by means of two closing forces such as-: (1) Stuffing box pressure acting on the rotating seal and (2) Mechanical force exerted by the springs. However, the same stuffing box pressure also tries to open the seal faces apart and there exists a thin stable liquid film between the faces. The pressure of this film is maximum where it enters the faces and it goes on decreasing as it approaches the atmospheric end of the seal faces. This gradually decreasing pressure wedge across the seal faces is called the "Pressure Gradient" and it is responsible for cooling and lubricating the seal faces. When this liquid film reaches the atmospheric end of the seal faces, its pressure reduces to such an extent that the liquid film vaporizes and thus no seal leak is virtually observed. Thus, the "Pressure Gradient" can be defined as the gradual pressure drop that takes place across the seal faces. The pressure progressively reduces from stuffing box pressure to the atmospheric pressure across the sealing faces

SEAL SELECTION PARAMETERS: While selecting a particular seal, the process parameters and the mechanical parameters are taken into consideration.

| Process parameters | Mechanical Parameters |
|---|---|
| Nature of the liquid | Stuffing box dimensions |
| Temperature | Speed |
| Pressure | Direction of rotation |
| PV Value | |

- ✓ Kindly refer API 610 & 682 for **mechanical seal leak rate –** A leakage rate of 10 drops per hour or less per seal is considered an acceptable leak rate for mechanical seal as per pump manufacturer .

## Mechanical seal API plan:

### API PLAN -01

**Description:** Integrated (internal) product recirculation from pump discharge to seal chamber.

**Features**

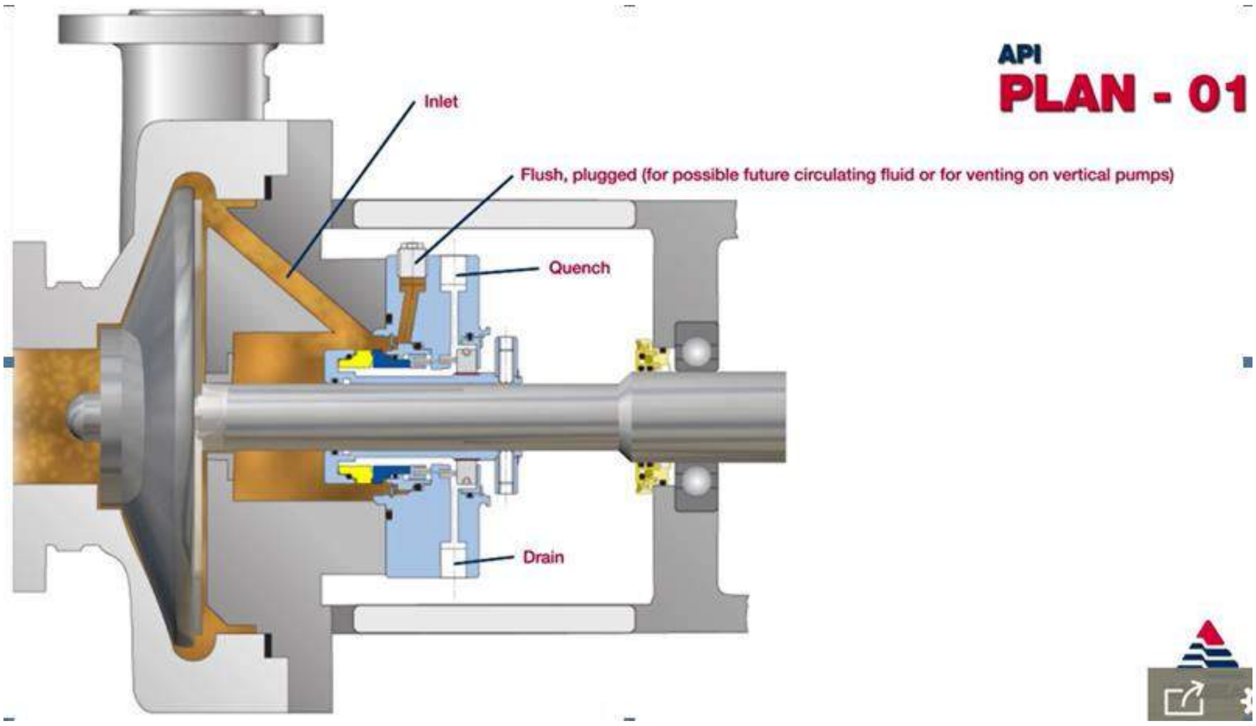
1. Minimizes risk of freezing / polymerizing of fluid in flush piping plans exposed to atmosphere.
2. Removes heat from the seal chamber as well as acting as a vent connection in horizontal pumps.

**Use**

1. Recommended in clean fluids.
2. Recommended for fluids which thicken at ambient temperature.

**Caution**

1. Ensure that the recirculation is sufficient for seal heat removal.


API
PLAN - 01
Inlet
Flush, plugged (for possible future circulating fluid or for venting on vertical pumps)
Quench
Drain

### API PLAN -02

**Description** : Dead ended seal chamber with no flush fluid circulation.

**Features**

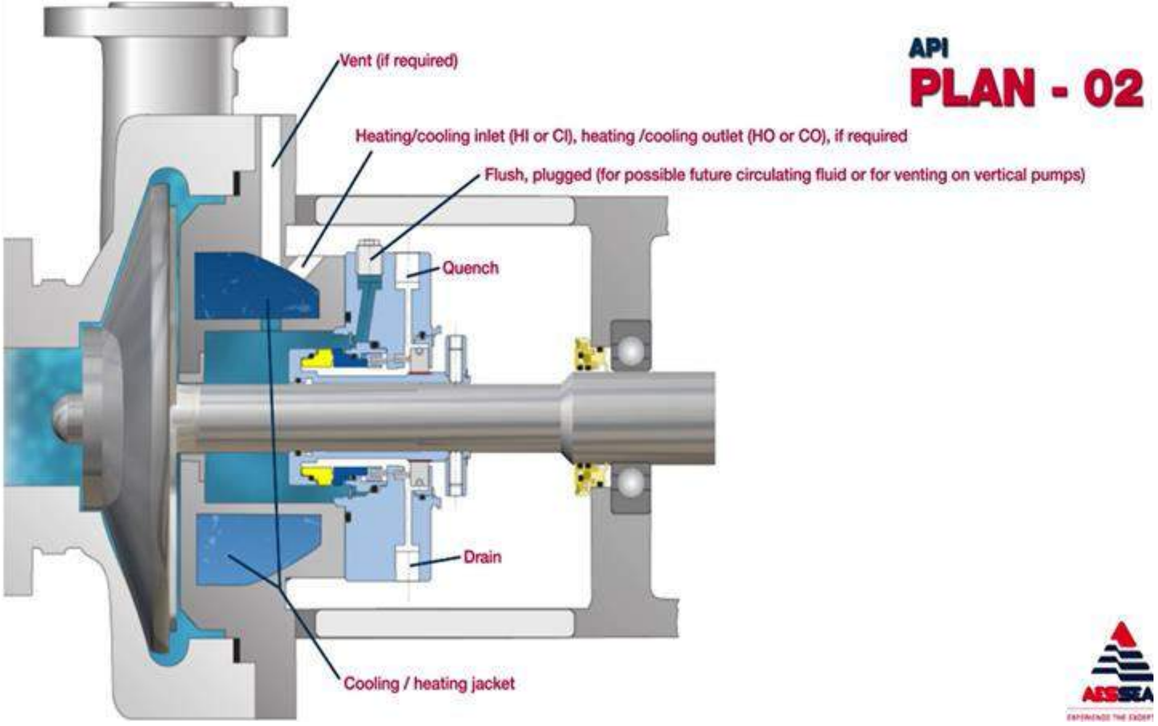
1. Applicable to low seal chamber pressure and process temperature.
2. Can be used with tapered seal chambers, especially for slurries.
3. Normally is used along with a jacketed seal chamber.

**Use**

1. in cool clean fluids with high specific heat, such as water, in relatively low speed pumps.

**Caution**

1. To avoid flashing, process fluid temperature must be taken into consideration.
2. Avoid use without cooling / heating jacket (for cylindrical chambers).
3. Ensure top point vent in throat bush (for cylindrical chambers in horizontal pumps).


API
PLAN - 02
Vent (if required)
Heating/cooling inlet (HI or CI), heating /cooling outlet (HO or CO), if required
Flush, plugged (for possible future circulating fluid or for venting on vertical pumps)
Quench
Drain
Cooling / heating jacket

## API PLAN -03

**Description** : Circulation between the seal chamber and pump is created by seal chamber design

**Features**

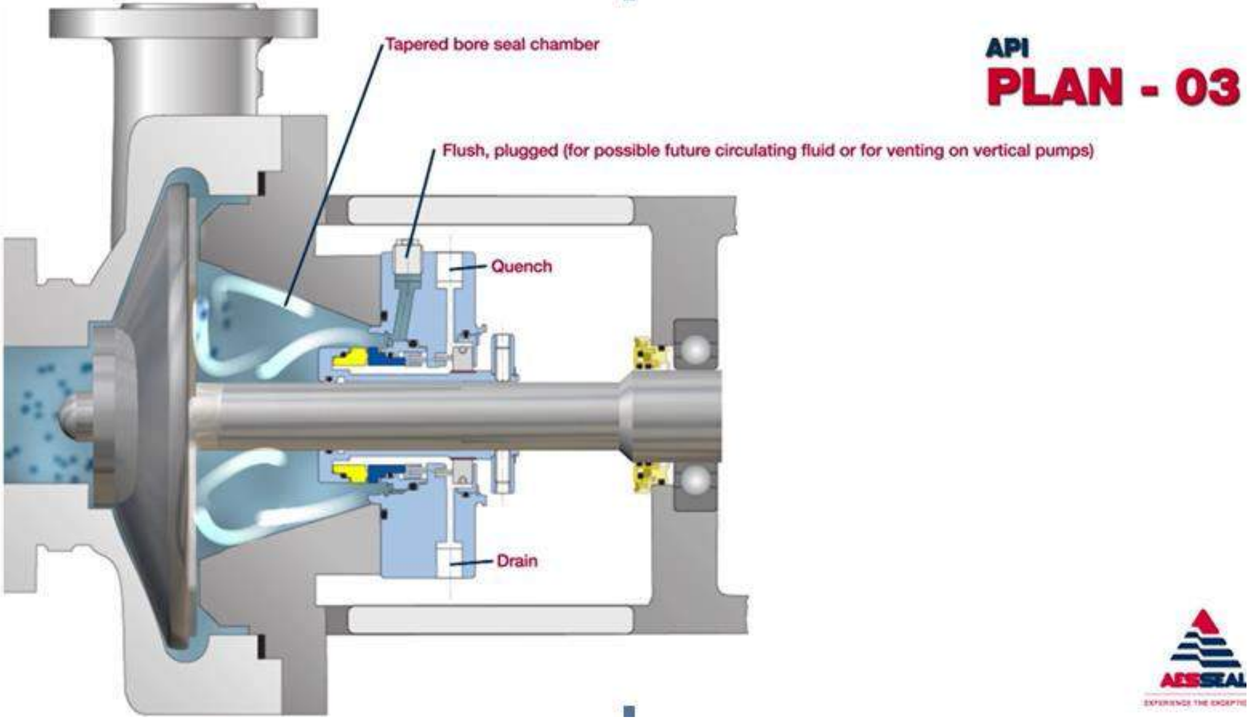
1. The mechanical seal is cooled by product flow created by seal chamber design.
2. Seal chamber design provides improved venting of air, air of vapors.

**Use**

1. Generally used in applications where there is not significant seal heat generated.
2. Solids could collect in traditional seal chamber.

**Caution**

1. Not suitable for cylindrical bore seal chambers.
2. May not be suitable for high pressure or high temperature seal chambers.


Tapered bore seal chamber
API
PLAN - 03
Flush, plugged (for possible future circulating fluid or for venting on vertical pumps)
Quench
Drain
AESSEAL

---

## API PLAN -11

**Description :** Product recirculation from pump discharge to seal through a flow control orifice.

**Features**

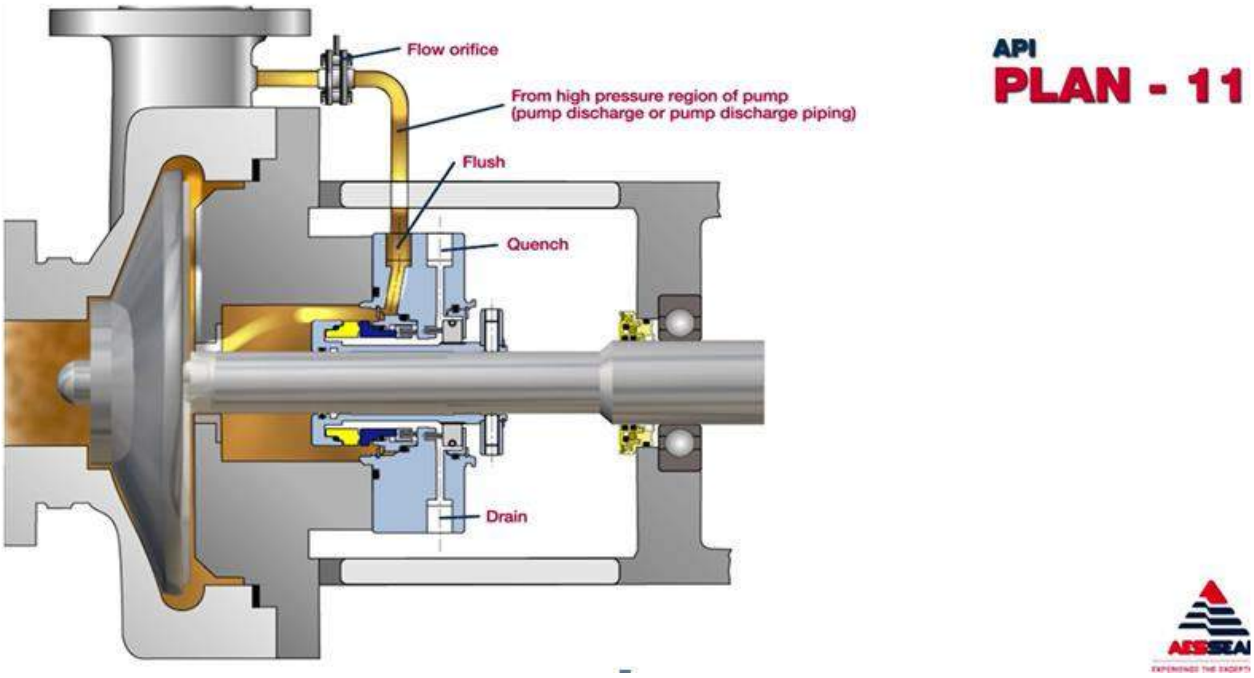
1. Prevents product from vaporizing by maintaining positive pressure above vapor pressure.
2. Becomes a self-venting plan for horizontal pumps.
3. Default API Plan for most single seals.

**Use**

1. In general, applications with clean non-polymerizing fluids with moderate temperatures.

**Caution**

1. Calculation of recirculation flow rate, heat removal and orifice size are required.
2. Orifice size should be at least 1/8” (3.2mm).
3. Check the margin between discharge pressure and seal chamber pressure to ensure proper flow of fluid.
4. Do not use with media containing solids and abrasives.


Flow orifice
From high pressure region of pump
(pump discharge or pump discharge piping)
Flush
Quench
Drain
API
PLAN - 11
AESSEAL

## API PLAN -12

**Description :** Product recirculation from pump discharge through a Y strainer and a flow control orifice to seal chamber.

**Features**

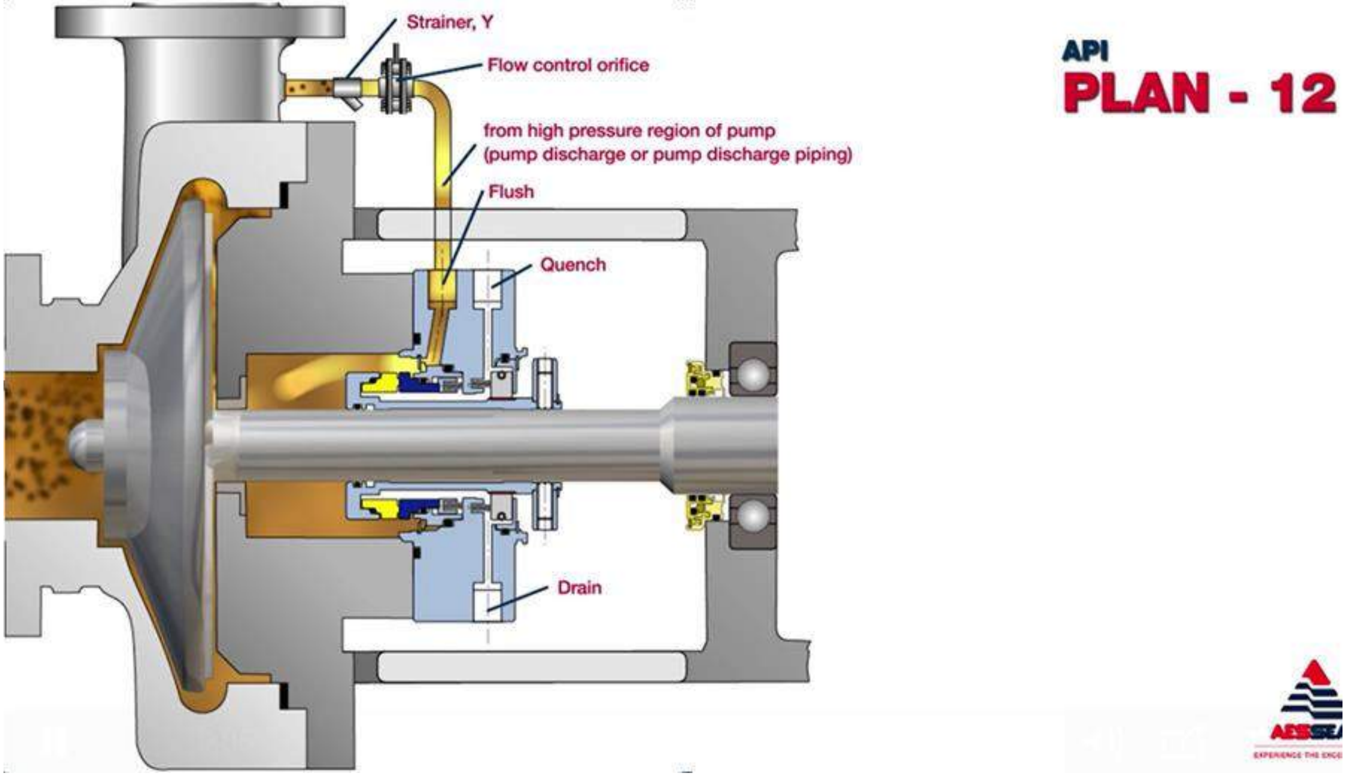
1. Becomes a self-venting plan for horizontal pumps.
2. Can handle dirty liquids to some extent.

**Use**

1. in general used in slightly dirty and non-polymerizing fluids.

**Caution**

1. Always ensure that orifice is placed after the Y strainer.
2. This plan is normally discouraged due to unreliability of Y strainer.
3. Calculation of recirculation is required.


Strainer, Y
Flow control orifice
from high pressure region of pump
(pump discharge or pump discharge piping)
Flush
Quench
Drain
API
PLAN - 12

---

## API PLAN -13

**Description** : Product recirculation from seal chamber to pump suction via a flow control orifice.

**Features**

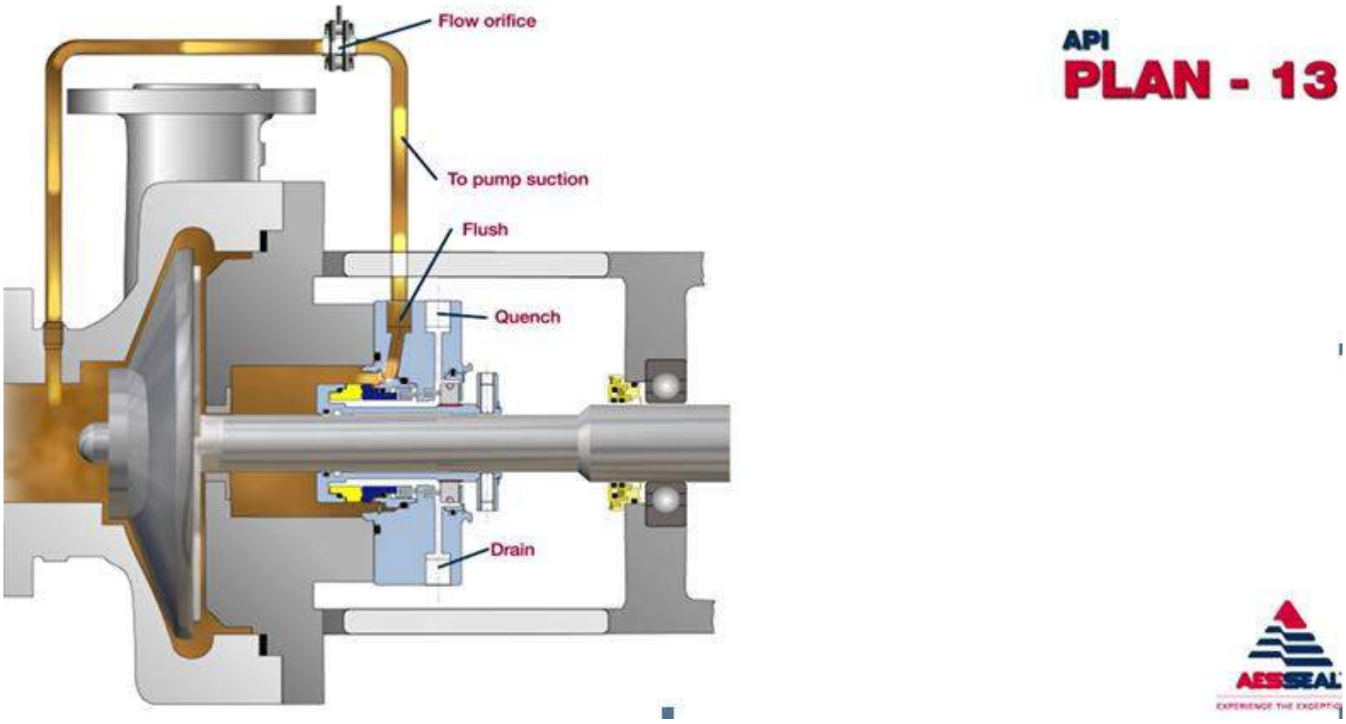
1. Provides continuous vent for vertical pumps.

**Use**

1. Wherever Plan 11 is not usable due to low-pressure margin between discharge and seal chamber pressure.
2. Used in vertical pumps.

**Caution**

1. Check margin between seal chamber pressure and suction pressure.
2. Orifice size should be at least 1/8” (3.2mm).


Flow orifice
To pump suction
Flush
Quench
Drain
API
PLAN - 13

## API PLAN -14

**Description :**Product recirculation from pump discharge to seal chamber through a flow control orifice and seal chamber back to suction through another flow control orifice.

**Features**

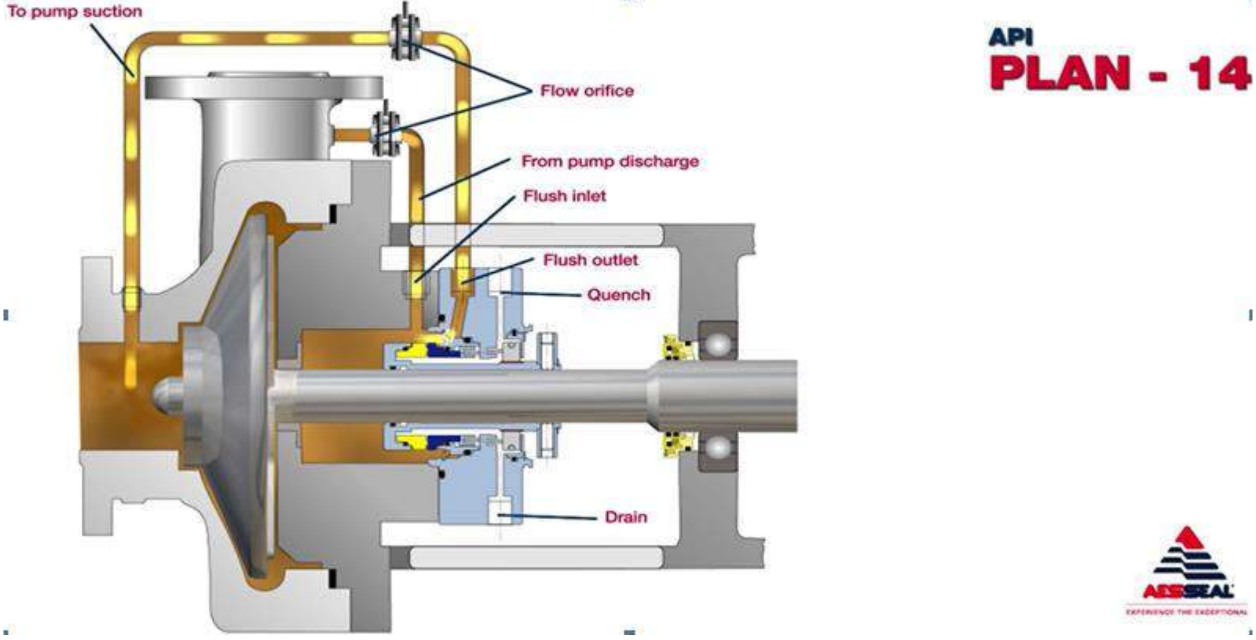
1. Ensures product recirculation as well as venting.
2. Reduces seal chamber pressure.

**Use**

1. Used in vertical pumps.
2. Used in light hydrocarbon services.

**Caution**

1. Check for pressure margin between discharge to seal chamber pressure and seal chamber to suction pressure.


To pump suction
Flow orifice
From pump discharge
Flush inlet
Flush outlet
Quench
Drain
API
PLAN - 14
AESSEAL

---

## API PLAN -21

**Description :** Product recirculation from discharge through flow control orifice and heat exchanger to seal chamber.

**Features**

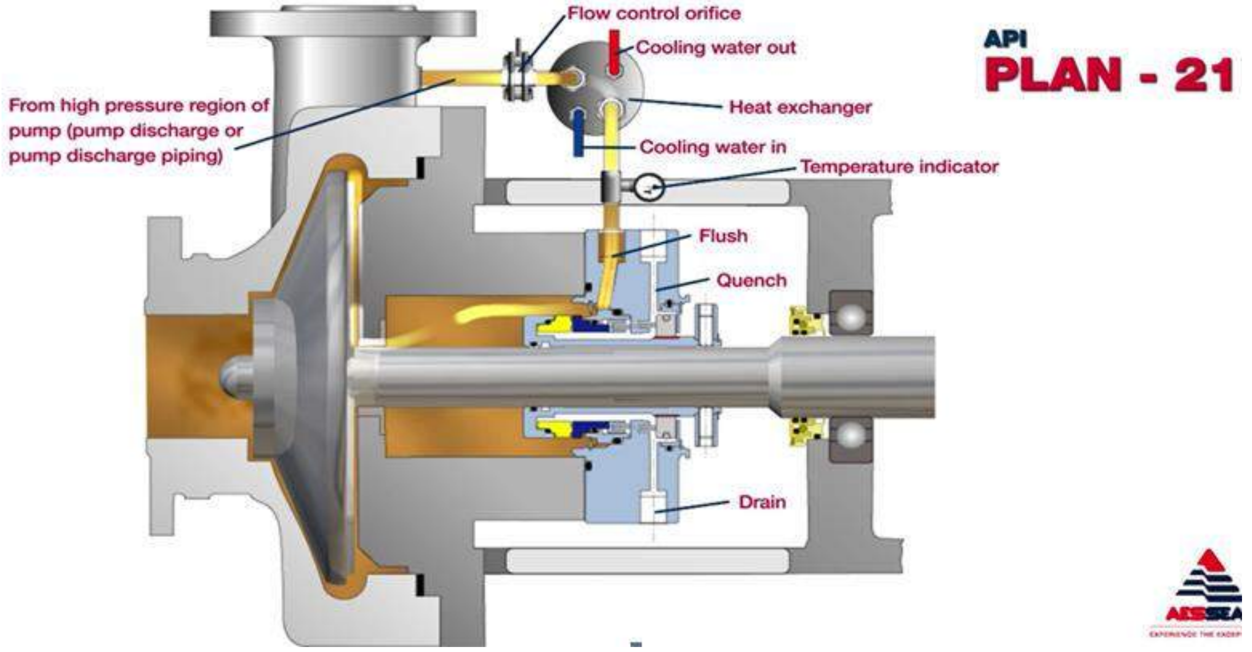
1. Improves pressure margin over vapor pressure.
2. Improves temperature margin to meet secondary sealing element limits, to reduce coking or polymerizing and to improve lubricity.
3. Self-venting plan.
4. Provides sufficient pressure difference to allow proper flow rate.

**Use**

1. For high temperature applications e.g. hot water application (temperature > 80ºC), hot hydrocarbons etc.
2. in hot non-polymerizing fluids.

**Caution**

1. Always ensure that cooler is placed after the orifice.
2. Check pressure difference between discharge and seal chamber.
3. Cooler duty is high leading to fouling on waterside.
4. Potential plugging on process side if fluid viscosity rises quickly.


Flow control orifice
Cooling water out
From high pressure region of pump (pump discharge or pump discharge piping)
Heat exchanger
Cooling water in
Temperature indicator
Flush
Quench
Drain
API
PLAN - 21
AESSEA

## API PLAN -22

**Description** : Product recirculation from pump discharge through a Y strainer, a flow control orifice and a heat exchanger to seal chamber.

**Features**

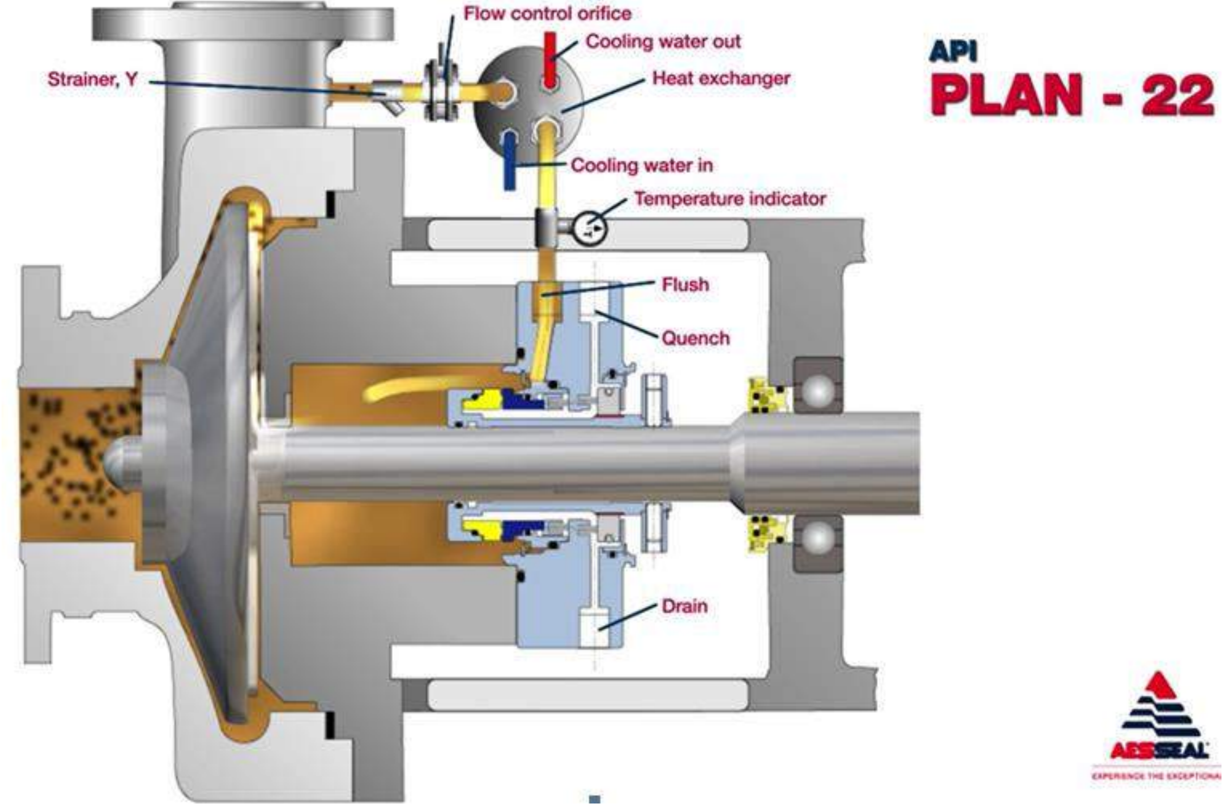
- Improves pressure margin over vapor pressure.
- Improves temperature margin to meet secondary sealing element limits, to reduce coking or polymerizing and to improve lubricity.
- Self-venting plan.
- Provides sufficient pressure difference to allow proper flow rate.

**Use**

1. For high temperature applications with slightly dirty liquid.

**Caution**

1. Always ensure that the orifice is placed after the Y strainer.
2. Always ensure that cooler is placed after the orifice.
3 .Check pressure difference between discharge and seal chamber.
4 Cooler duty is leading to fouling on waterside.
5 This plan is normally discouraged due to non-reliability of Y strainer



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## API PLAN -23

**Description** : Product recirculation from seal chamber to heat exchanger and back to seal chamber.

**Features**

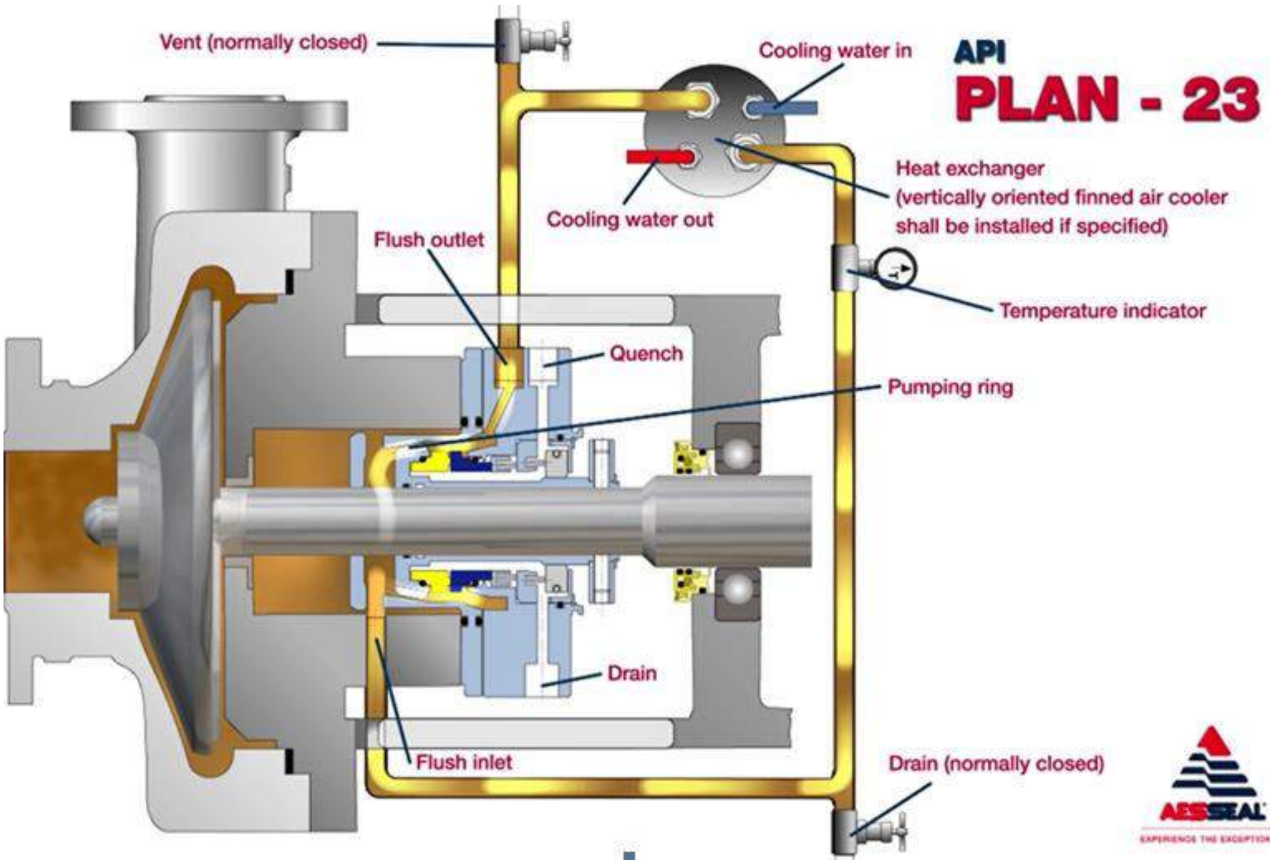
1. Circulation is maintained by pumping ring.
2. In idle condition heat transfer is maintained by thermosiphon effect and in running condition by a pumping ring.
3. Lower product stabilization temperature is achieved.
4. Establishes required margin between fluid vapor pressure and seal chamber pressure.

**Use**

1. In hot and clean services e.g. in boiler feed water and hot hydrocarbon services.

**Caution**

1. Maintain maximum 0.5m horizontal distance from seal chamber to heat exchanger.
2. Vent valve required at highest point of piping system.
3. Ensure that pump has a close clearance throat bush.
4. Ensure that the seal outlet connection is in the top half of the gland.
5. Ensure that the cooler is mounted above the pump center line.
6. Vent the system fully before start up.


Vent (normally closed)
Cooling water in
API
PLAN - 23
Heat exchanger
(vertically oriented finned air cooler
shall be installed if specified)
Cooling water out
Flush outlet
Temperature indicator
Quench
Pumping ring
Drain
Flush inlet
Drain (normally closed)
AESSEAL
EXPERIENCE THE EXCEPTION

## API PLAN -31

**Description** :Product recirculation from discharge through a cyclone separator, which directs clean fluid to the seal and solids back to pump suction.

**Features**

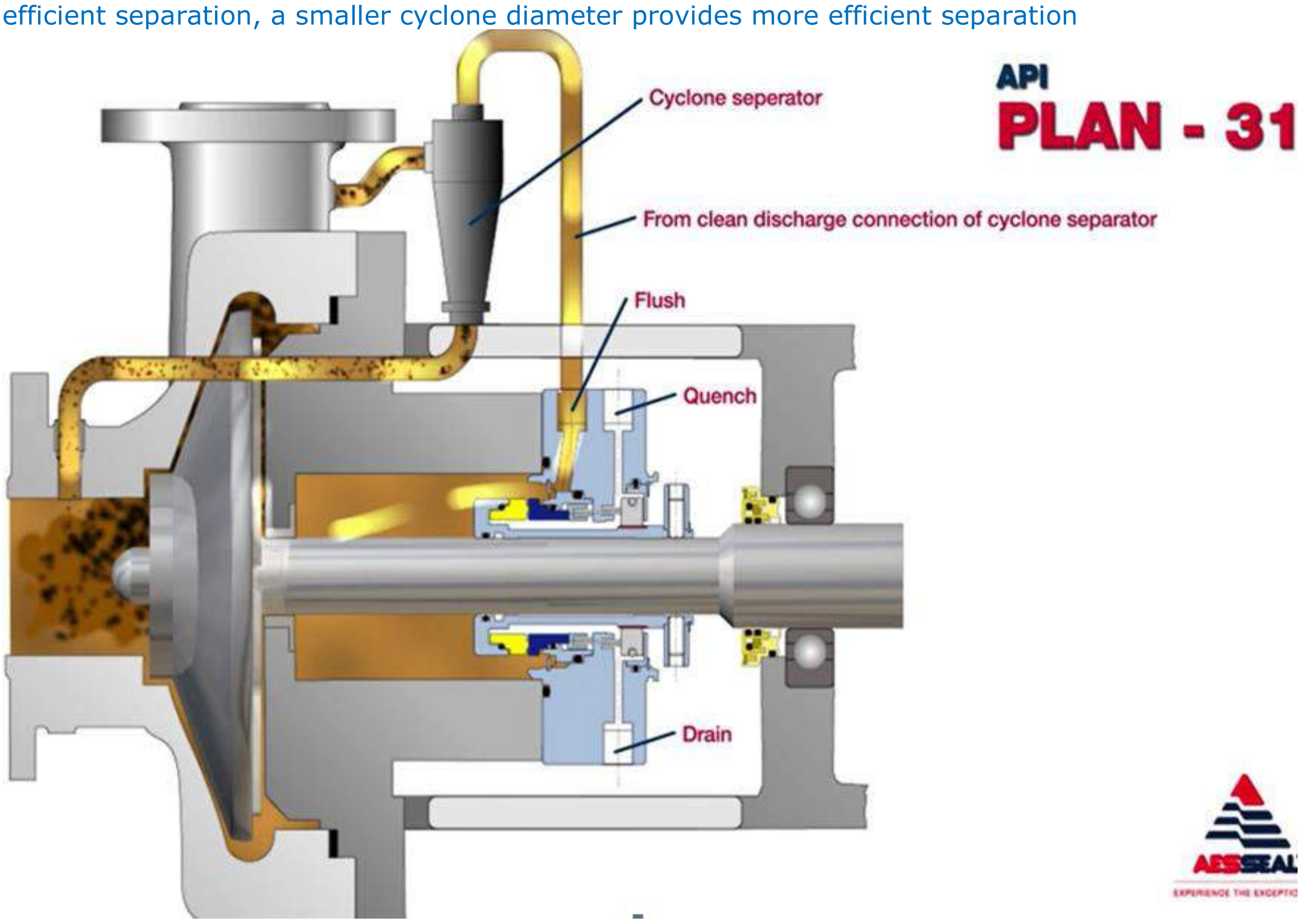
1. Removes entrained solids from the process fluid.
2. Particles from cyclone separator are returned to suction.

**Use**

1. Used in media with suspended solids.

**Caution**

1. Pump throat bushing is recommended.
2. Ensure use for services containing solids with specific gravity twice or more than that of process fluid.
3. Efficiency of a cyclone separator is proportional to the diameter. A larger cyclone diameter leads to less efficient separation, a smaller cyclone diameter provides more efficient separation


Cyclone seperator
API
PLAN - 31
From clean discharge connection of cyclone separator
Flush
Quench
Drain
AESSEAL
EXPERIENCE THE EXCEPTION

## API PLAN -32

**Description** : Injection of clean or cool liquid from external source into the seal chamber.

**Features**

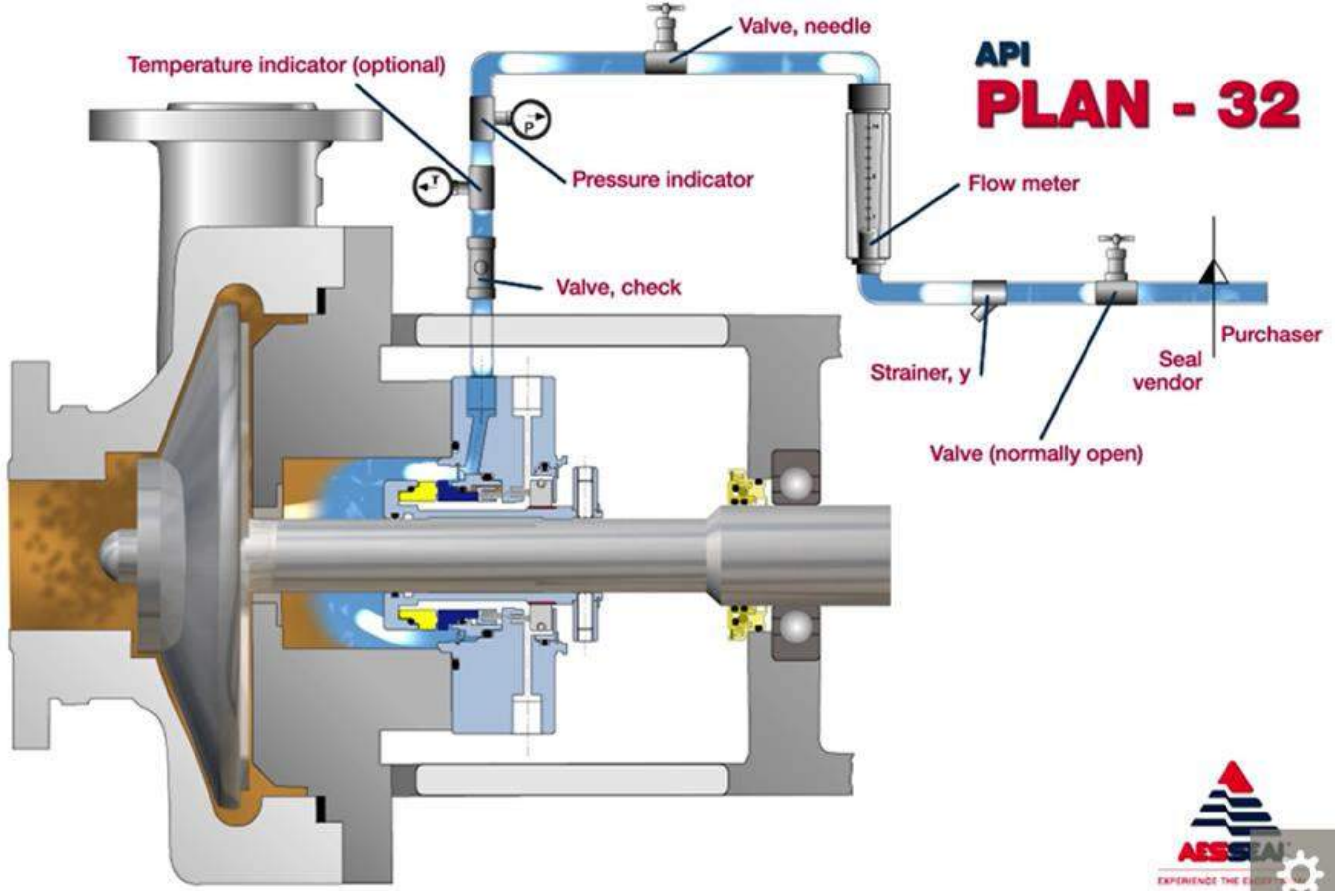
1. Reduces flashing or air intrusion across seal faces by providing a positive flush.
2. Maintains vapor pressure margin.
3. Always provided at a pressure greater than seal chamber pressure.
4. If maintained properly the best of all single seal plans (subject to acceptance of contamination).

**Use**

1. Dirty or contaminated fluids.
2. High temperature applications.
3. Polymerizing and oxidizing fluids.
4. Media with poor lubrication properties.

**Caution**

1. External source should be continuous and reliable at all times, even during start up and shut down.
2. Flush fluid must be compatible with process fluid due to product contamination.
3. Product degradation can occur.
4. Ensure use with close clearance throat bushing to maintain pressure in stuffing box and control the rate of contamination of pumped media.
5. Careful selection of flush fluid required to ensure that it does not vaporize on entering the seal chamber.
6. Fluid expenditure of Plan 32 may be as expensive as one or more seals per year.



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## API PLAN -41

**Description :** Product recirculation from discharge through a cyclone separator and a heat exchanger to seal chamber.

**Features**

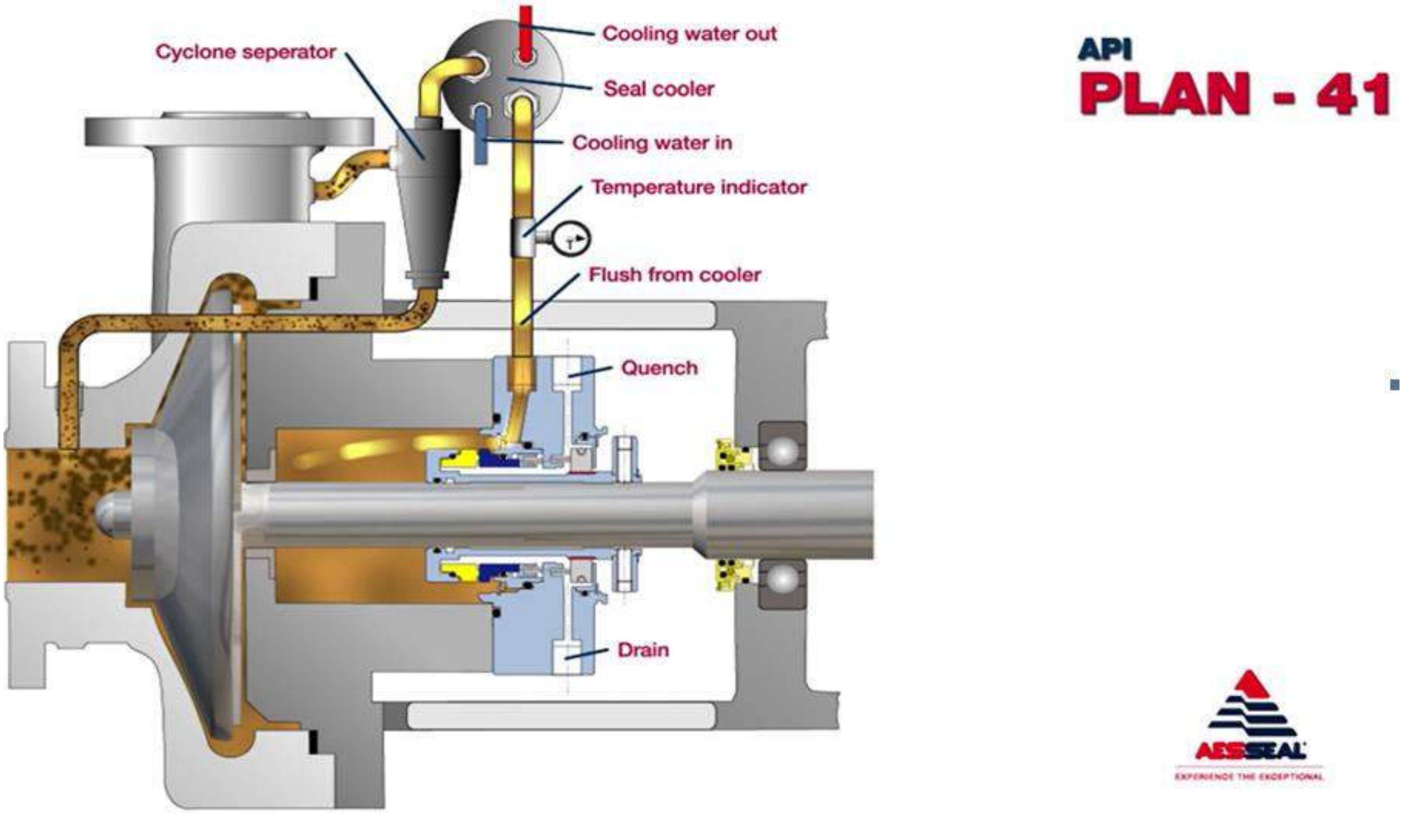
1. Improves pressure margin to vapor pressure.
2. Improves temperature margin to meet secondary sealing element limits, to reduce coking or polymerizing and to improve lubricity.
3. Removes entrained solids from the process fluid.
4. Particles from cyclone separator are returned to suction.

**Use**

1. In hot services containing suspended solids.

**Caution**

1. Pump throat bushing is recommended.
2. Ensure use for services containing solids with specific gravity twice or more than that of process fluid.
3. Cooler duty is high leading to fouling on waterside.


Cyclone seperator
Cooling water out
Seal cooler
Cooling water in
Temperature indicator
Flush from cooler
Quench
Drain
API
PLAN - 41
AESSEAL
EXPERIENCE THE EXCEPTIONAL

## API PLAN -51

**Description :** External reservoir providing a dead-ended blanket for fluid to the quench connection of the gland.

**Features**

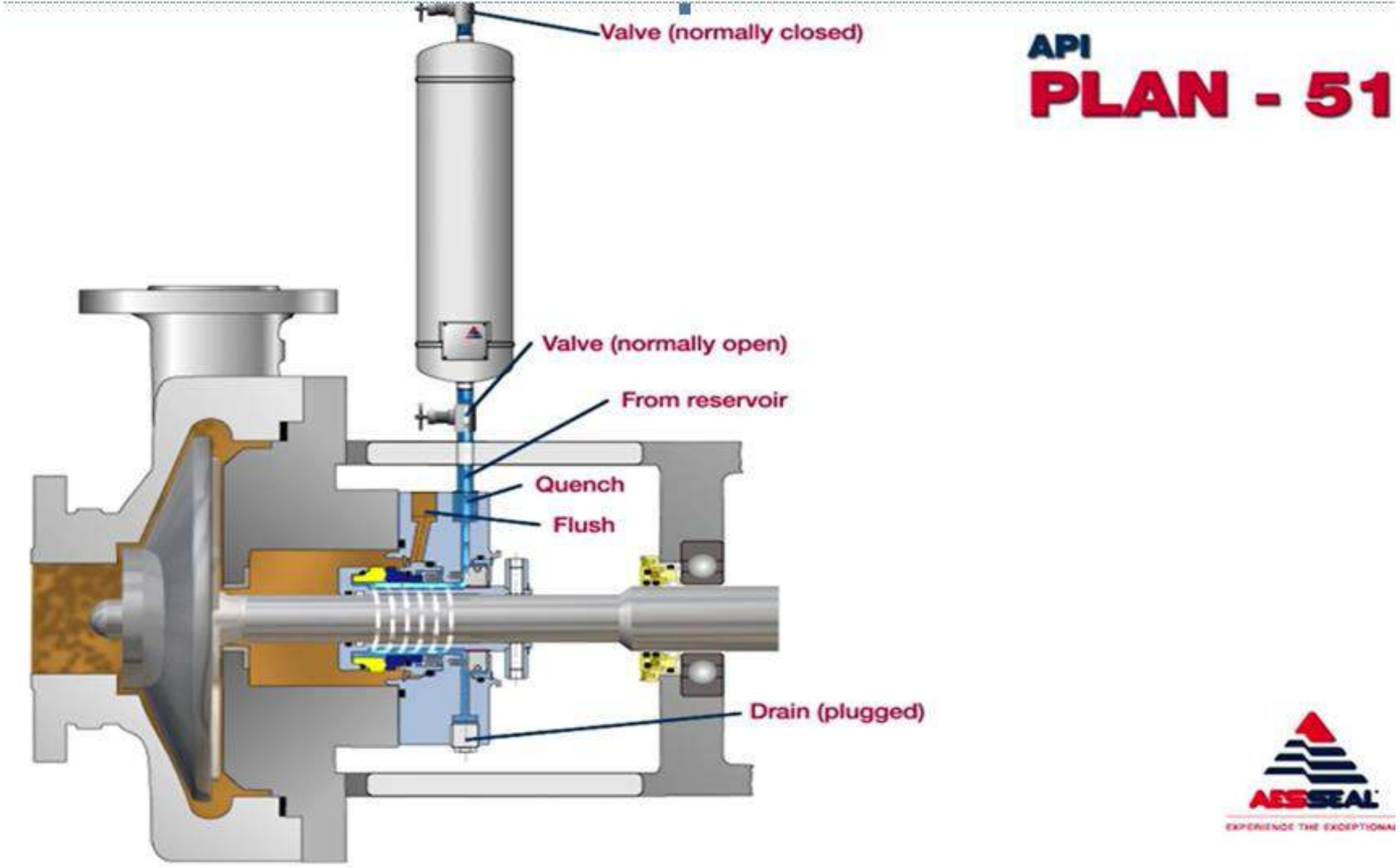
1. No direct process leakage to atmosphere.
2. No need to maintain pressure system as in Plan 53A.

**Use**

1. Preferred for clean, non-polymerizing media with vapor pressure higher than buffer fluid pressure.

**Caution**

1. Keep pot vent continuously open, which is necessary to maintain buffer fluid pressure close to atmospheric pressure and vent the vapors to flare.
2. Should not be used with dirty or polymerizing products.
3. Never run the system with level in the sealant vessel at low level as marked on the level gauge.
4. Vent the system properly before start up


Valve (normally closed)
API
PLAN - 51
Valve (normally open)
From reservoir
Quench
Flush
Drain (plugged)
AESSEAL
EXPERIENCE THE EXCEPTIONAL

## API PLAN -52

**Description** :Depressurized buffer fluid circulation in outboard seal of a dual seal configuration through a seal support system. Circulation is maintained by using pumping ring in running condition and by thermosiphon effect in stand still condition.

**Features**

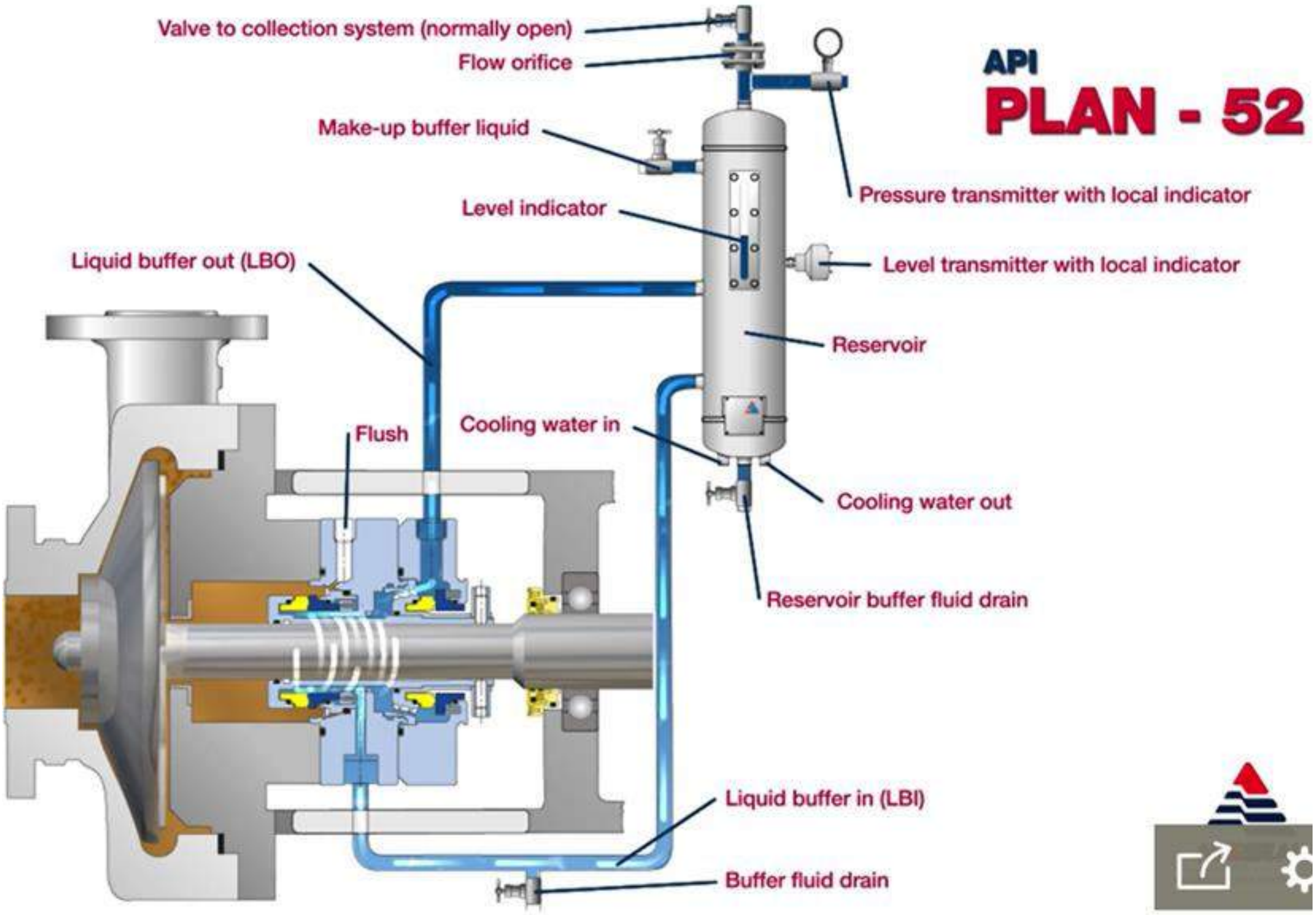
1. No process contamination.
2. No direct process leakage to atmosphere.
3. No need to maintain pressure system as in Plan 53A.

**Use**

1. For media where product dilution is not allowed but leakage to atmosphere in diluted form may be allowed.
2. Preferred for clean, non-polymerizing media with vapor pressure higher than buffer fluid pressure (Is also used for lower vapor pressure media).

**Caution**

1. Keep the sealant vessel vent continuously open, which is necessary to maintain buffer fluid pressure close to atmospheric pressure and vent the vapors to flare.
2. Should not be used in dirty or polymerizing products.
3. A restriction orifice is necessary in vent line to maintain back pressure in pot and facilitate quick release of vapors to flare.
4. Pressure switch setting should be done above minimum flare back pressure in order to avoid false alarms.
5. Never run the system with level in the sealant vessel being at low level as marked on the level gauge.
6. Check for temperature difference in inlet and outlet lines to ensure that circulation is on.
7. Vent the system properly before start up.


Valve to collection system (normally open)
Flow orifice
Make-up buffer liquid
Level indicator
Liquid buffer out (LBO)
Flush
Cooling water in
API
PLAN - 52
Pressure transmitter with local indicator
Level transmitter with local indicator
Reservoir
Cooling water out
Reservoir buffer fluid drain
Liquid buffer in (LBI)
Buffer fluid drain

---

## API PLAN -53 A

**Description** :Pressurized barrier fluid circulation in outboard seal of dual seal configuration through a seal support system. Circulation is maintained by using pumping ring in running condition and with thermosiphon effect in stand still condition.

**Features**

1. In no case will media leak to atmosphere (Provided the seal support system pressure is not lost).
2. Clean fluid film formation between the inboard seal faces gives better seal life.
3. Works as a Plan 52 arrangement if barrier fluid pressure is lost.

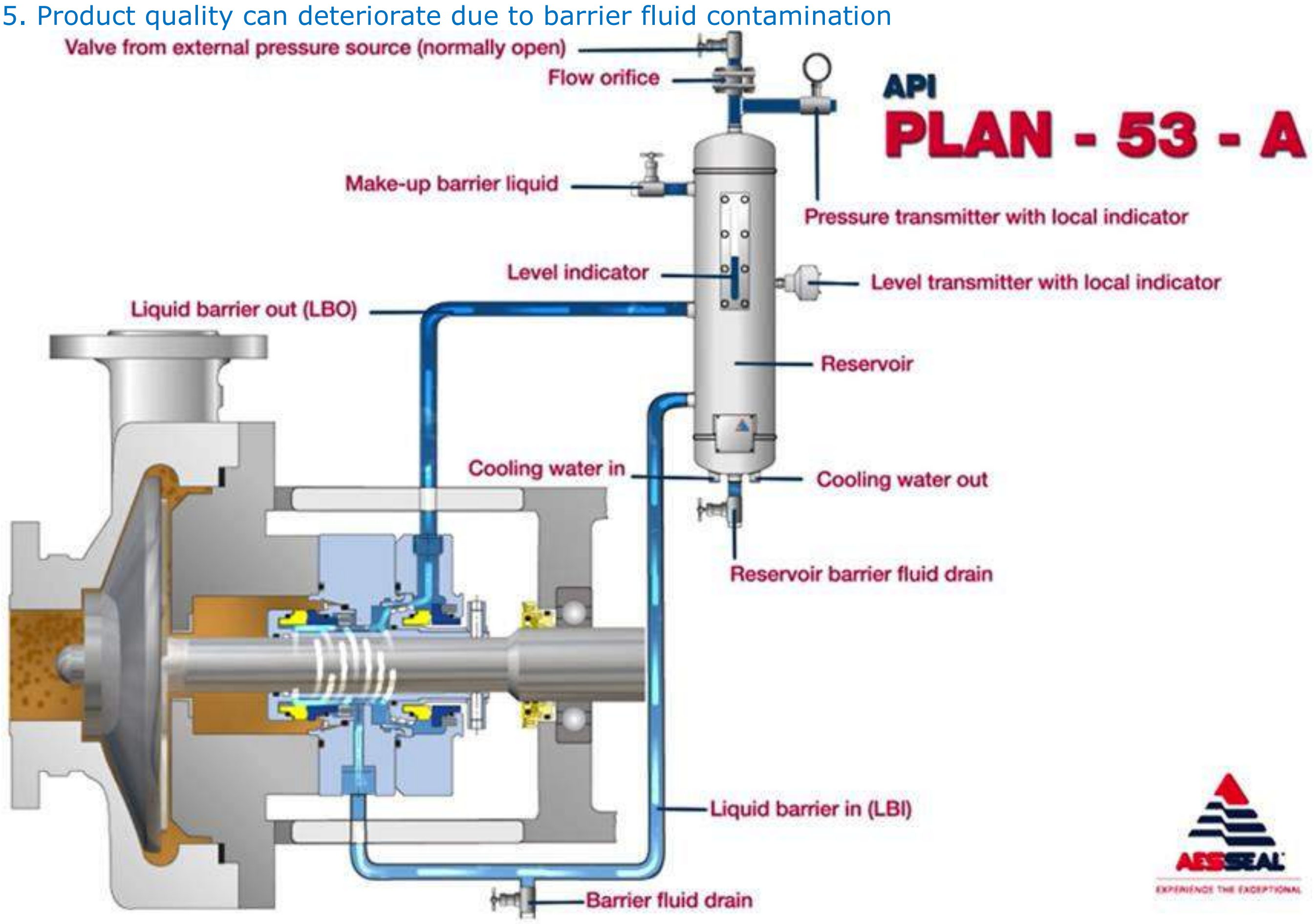
**Use**

1. Applications where no leakage to atmosphere can be tolerated e.g. hazardous, toxic, inflammable media.
2. For dirty, abrasive or polymerizing products where media is unsuitable as a lubricant for inboard seal faces.

**Caution**

1. There will always be some leakage of barrier fluid into the product. Check compatibility of barrier fluid with product.
2. Always ensure that the pressure source maintains higher pressure at the seal support system so that

process does not dilute the barrier fluid.
3. Vent the system properly before start up.
4. In certain cases the inert gas can dissolve in the barrier media.
5. Product quality can deteriorate due to barrier fluid contamination


Valve from external pressure source (normally open)
Flow orifice
API
PLAN - 53 - A
Make-up barrier liquid
Pressure transmitter with local indicator
Level indicator
Level transmitter with local indicator
Liquid barrier out (LBO)
Reservoir
Cooling water in
Cooling water out
Reservoir barrier fluid drain
Liquid barrier in (LBI)
Barrier fluid drain
AESSEAL
EXPERIENCE THE EXCEPTIONAL

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## API PLAN -53 B

**Description** : Pressurized barrier fluid circulation in outboard seal of dual seal configuration. Circulation is maintained by using pumping ring in running condition and with thermosiphon effect in stand still condition. The pressure is maintained in the seal circuit by a bladder accumulator.

**Features**

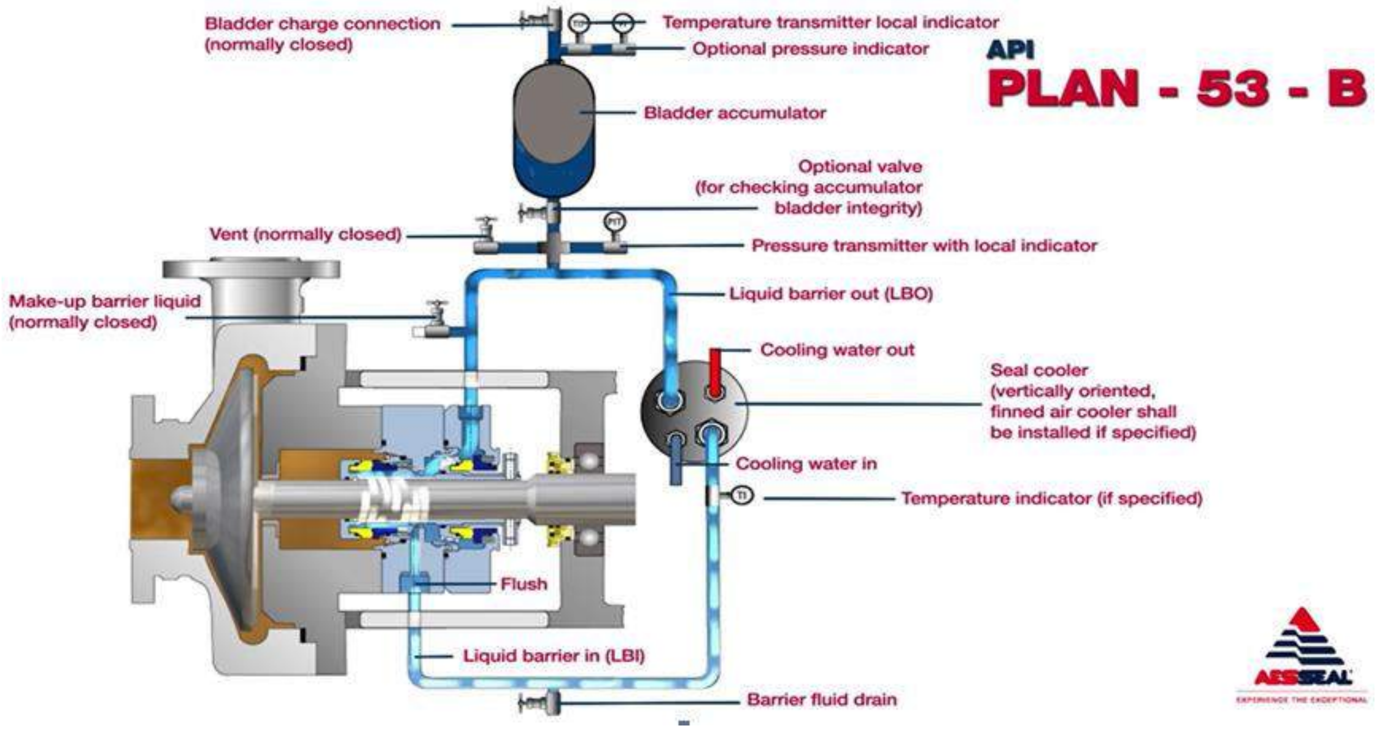
1. Keeps barrier fluid and pressurized gas (inert gas) separate by using a bladder.
2. Heat is removed from the circulation system by an air-cooled or water-cooled heat exchanger.
3. Being a stand-alone system does not rely upon a central pressure source. Hence much more reliable than a Plan 53A.
4. In no case will media leak to atmosphere.
5. Clean fluid film formation between the inboard seal faces gives better seal life.

**Use**

1. Applications where no leakage to atmosphere can be tolerated e.g. hazardous, toxic, inflammable media.
2. For dirty, abrasive or polymerizing products where media is unsuitable as a lubricant for inboard seal faces.

**Caution**

1. There will always be some leakage of barrier fluid into the product. Check compatibility of barrier fluid with product.
2. Low volume of barrier fluid in system, hence heat dissipation is totally dependent on cooler efficiency.
3. Always recharge bladder to 0.9 times the working pressure.
4. Vent the system properly before start up.
5. Product quality can deteriorate due to barrier fluid contamination.


Bladder charge connection (normally closed)
Temperature transmitter local indicator
Optional pressure indicator
API
PLAN - 53 - B
Bladder accumulator
Optional valve (for checking accumulator bladder integrity)
Vent (normally closed)
Pressure transmitter with local indicator
Make-up barrier liquid (normally closed)
Liquid barrier out (LBO)
Cooling water out
Seal cooler (vertically oriented, finned air cooler shall be installed if specified)
Cooling water in
Temperature indicator (if specified)
Flush
Liquid barrier in (LBI)
Barrier fluid drain

---

## API PLAN -53 C

**Description :** Pressurized barrier fluid circulation in outboard seal of dual seal configuration. Circulation is maintained by using pumping ring in running condition and with thermosiphon effect in stand still condition. The pressure is maintained and fluctuations are compensated in the seal circuit by a piston type accumulator.

**Features**

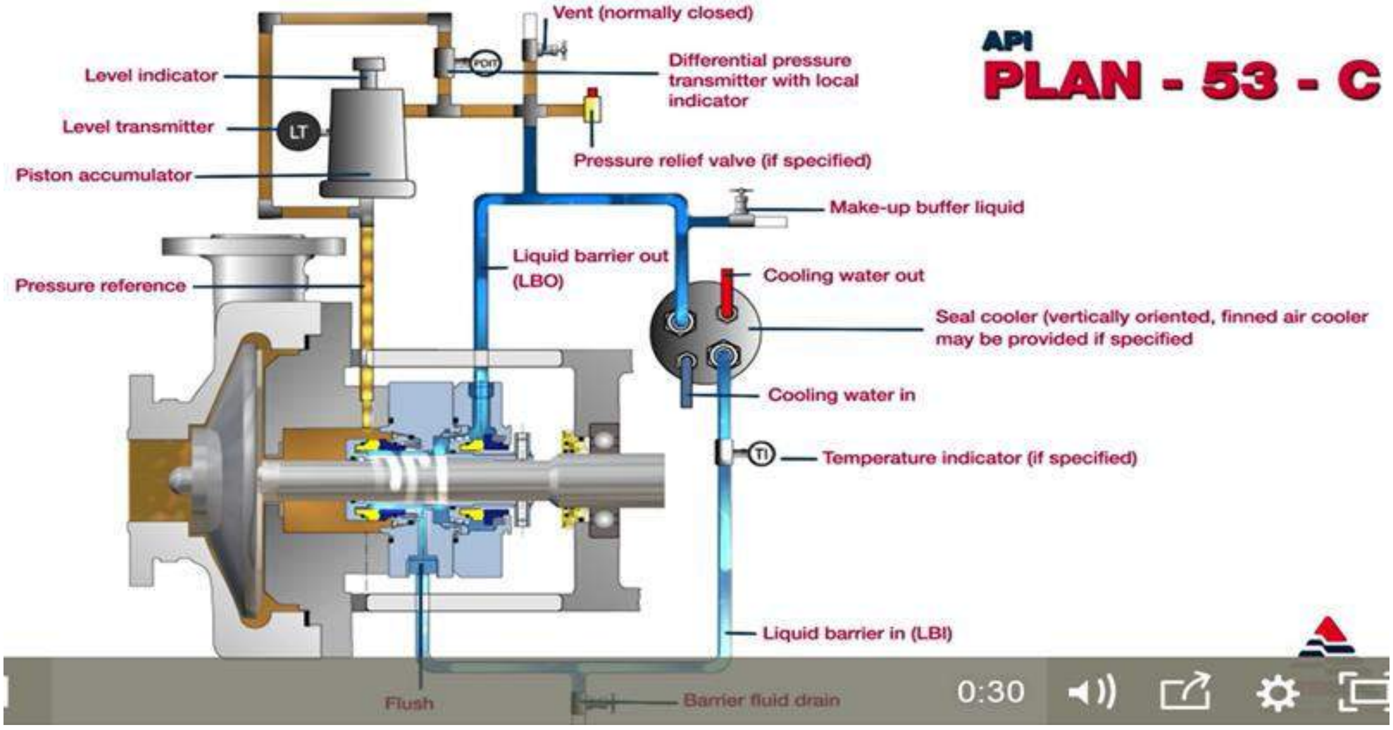
1. Vent system properly before start up.
2. Heat is removed from the circulation system by an air-cooled or water-cooled heat exchanger.
3. In no case will the media leak to the atmosphere.
4. Clean fluid film formation between the inboard seal faces gives better seal life.
5. This allows successful operation of dual seals lacking reverse balance feature at inboard seal, when having highly variable seal chamber pressure.

**Use**

1. Applications where no leakage to atmosphere can be tolerated e.g. hazardous, toxic, inflammable media.
2. For dirty, abrasive or polymerizing products where media is unsuitable as a lubricant for inboard seal faces.
3. Where pump pressure varies during operation needing an auto setting of barrier fluid pressure, thus maintaining the same differential throughout.

**Caution**

1. Always connect reference pressure line from seal chamber to accumulator and keep it open.
2. There will always be some leakage of barrier fluid into the product. Check compatibility of barrier fluid with product.
3. Vent the system properly before start up.
4. Product quality can deteriorate due to barrier fluid contamination


Vent (normally closed)
Level indicator
Differential pressure transmitter with local indicator
API
PLAN - 53 - C
Level transmitter
LT
Piston accumulator
Pressure relief valve (if specified)
Make-up buffer liquid
Liquid barrier out (LBO)
Pressure reference
Cooling water out
Seal cooler (vertically oriented, finned air cooler may be provided if specified
Cooling water in
Temperature indicator (if specified)
Liquid barrier in (LBI)
Flush
Barrier fluid drain
0:30

## API PLAN -54

**Description:** Pressurized external barrier fluid circulation from a central pressure source or by a stand-alone pumping unit.

**Features:**

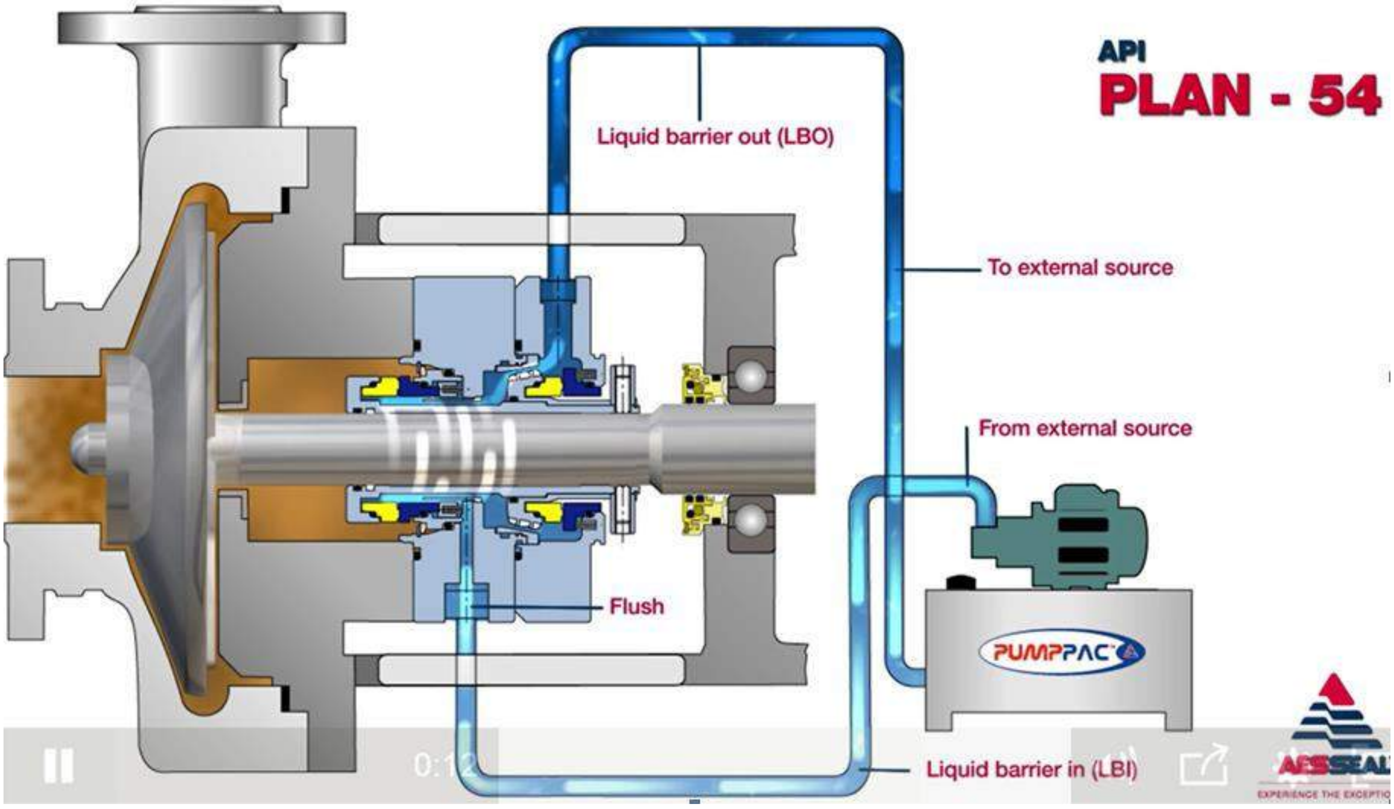
1. Ensures higher flow rate, better heat dissipation and positive circulation of barrier fluid.
2. If maintained properly, is the most reliable pressurized plan for dual seals as compared to Plan 53 A/B/C.
3. Can also be given as a stand-alone unit per pump.
4. Increases cooler efficiency due to higher flow rate the heat exchanger.

**Uses:**

1. Applications where no leakage to atmosphere can be tolerated e.g. hazardous, toxic, inflammable.
2. for dirty, abrasives or polymerizing products where media is unsuitable as a lubricant for inboard seal faces.
3. for media with high pressure and / or high temperature and / or high heat generation between faces.
4. Wherever Plan 53 A/B/C circulation is insufficient to dissipate heat.

**Caution:**

1. Carefully consider the reliability of barrier fluid source, if a central source is used.
2. Expensive system, proper engineering required.
3. Circulating system must be pressurized at least 1.5 bar greater that the pressure in the seal chamber.
4. Product contamination does occur. Barrier fluid selected should be compatible with the process fluid.
5. Always check filter / strainer in the system for any possible blockages.
6. Loss of pressure in system can lead to entire barrier liquid contamination.
7. Product quality can deteriorate due to barrier fluid contamination.



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## API PLAN -55

**Description :** Unpressurised external barrier fluid circulation from a central source.

**Features**

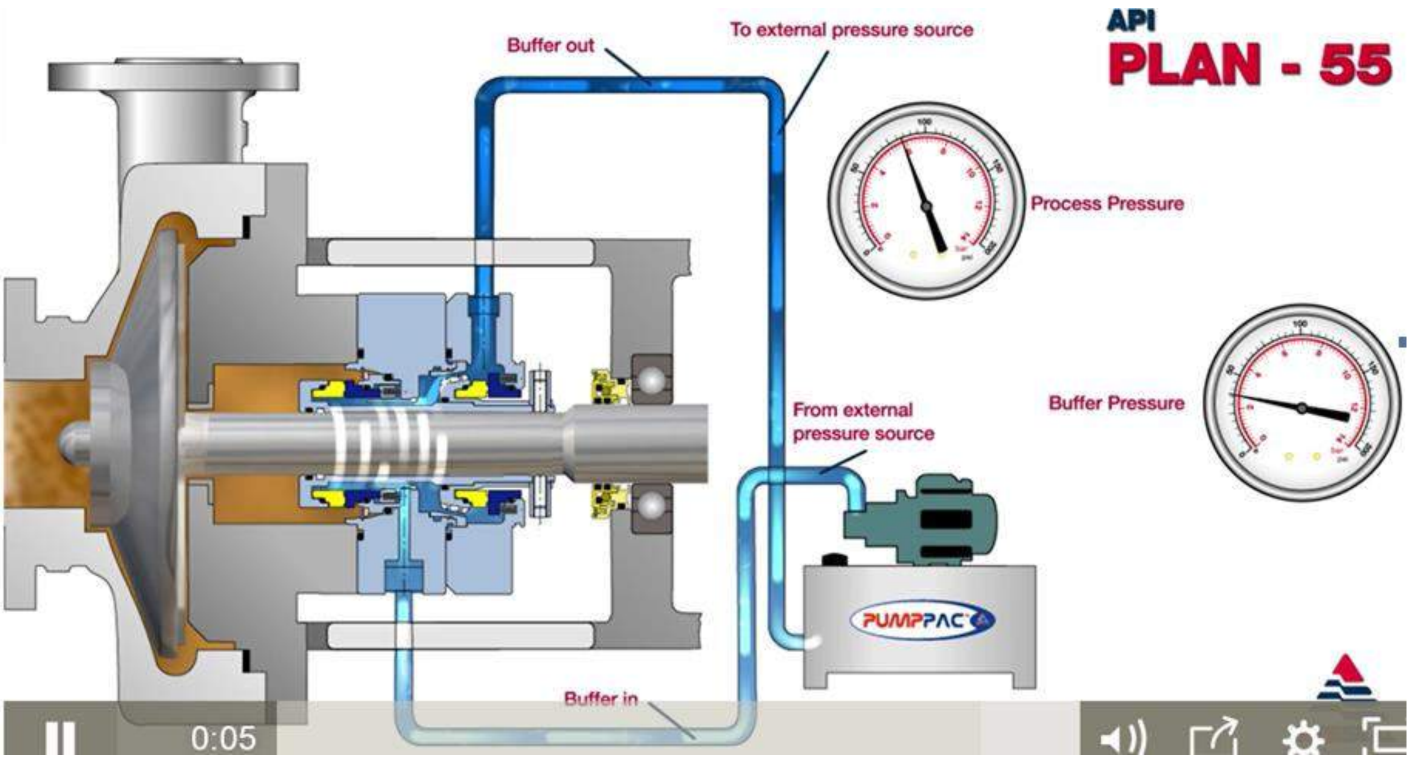
- 1. Ensures higher flow rate, better heat dissipation and positive circulation of buffer fluid.
- 2. Buffer fluid maintained less than seal chamber pressure and less than 2.8 bar.
- 3.Increases cooler efficiency due to higher flow rate to the heat exchanger
- 4. Process fluid does not leak directly to atmosphere.

**Uses**

- 1. For media where product dilution is not allowed but leakage to atmosphere diluted form may be allowed.
- 2. Preferred for clean, non-polymerizing with high vapor pressure.
- 3. May also be used for non-flashing products.
- 4. for media with high temperature and/or high heat generation between faces.

**Caution**

- 1. Carefully consider reliability of buffer fluid source.
- 2. Should not be used for dirty or polymerizing products.
- 3. Ensure product is compatible with buffer media.


API
PLAN - 55
Buffer out
To external pressure source
Process Pressure
Buffer Pressure
From external
pressure source
PUMPPAC
Buffer in
0:05

## API PLAN -61

**Description :** Plugged connections for future use for Plan 62 or Plan 65.

**Features**

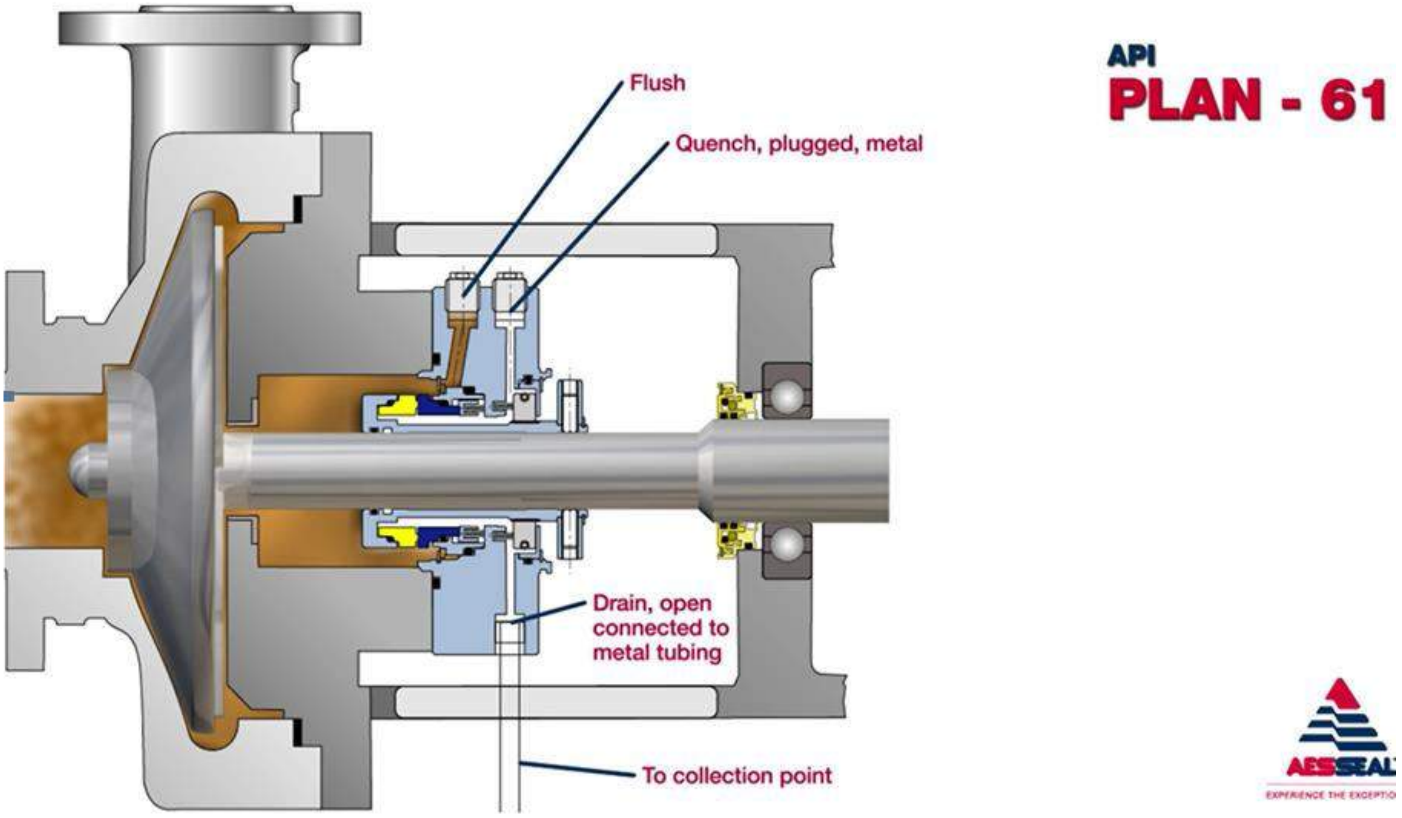
1. The drain connection can be piped in order to collect leakage and use as Plan 65.
2. Both quench and drain can be piped and used as quench in and out connection as Plan 62.

**Use**

1. for future provision.

**Caution**

1. Always keep ports plugged.


API
PLAN - 61
Flush
Quench, plugged, metal
Drain, open
connected to
metal tubing
To collection point
AESSEAL
EXPERIENCE THE EXCEPTIO

## API PLAN -62

**Description :**An external fluid stream is brought to atmospheric side of the seal faces using quench and drain connections.

**Features**

1. The quench fluid acts as barrier in between atmosphere and process fluid.
2. The quench fluid reduces oxidation and coking of product and also cools seal faces.
3. Flushes away undesirable material build up under seal faces.
4. Can be used with water, steam or an inert gas.

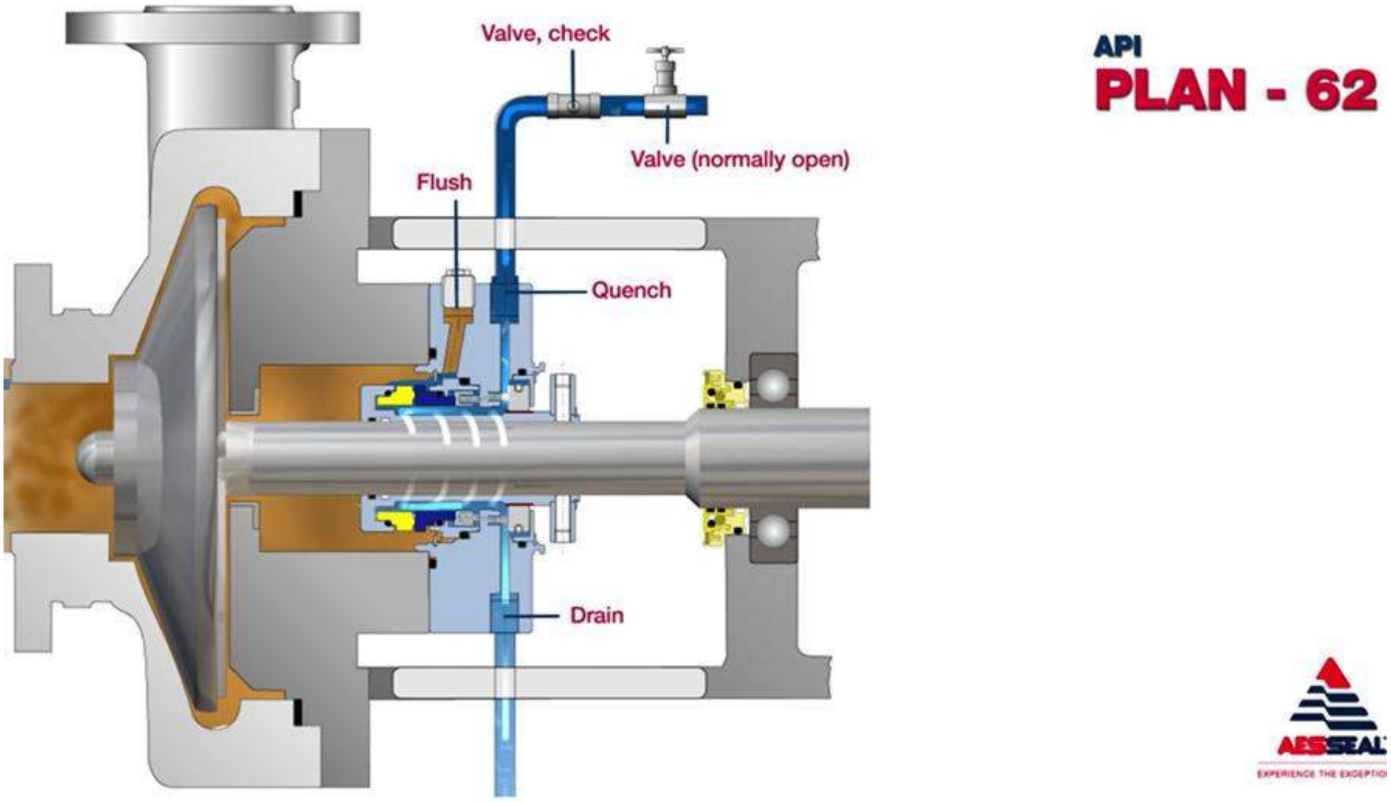
**Use**

1. in caustic or crystallizing fluids.

2. in oxidizing fluids or hot hydrocarbons.
3. Can be used to purge steam in hot applications especially for stationary bellows to avoid coking.

**Caution**

1. Ensure availability of continuous supply of low-pressure quench fluid limited to maximum 1 bar.
2. Use of throttle bushing on atmosphere side is mandatory.
3. Use proper bearing isolators to ensure that the quench fluid does not enter the bearings


Valve, check
Valve (normally open)
Flush
Quench
Drain
API
PLAN - 62
AESSEAL
EXPERIENCE THE EXCEPTIO

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## API PLAN -65 A

**Description :** Leakage from seal faces is directed to a liquid collection system. A vessel with a high level alarm is Provided for detection of excess leakage.

**Features**

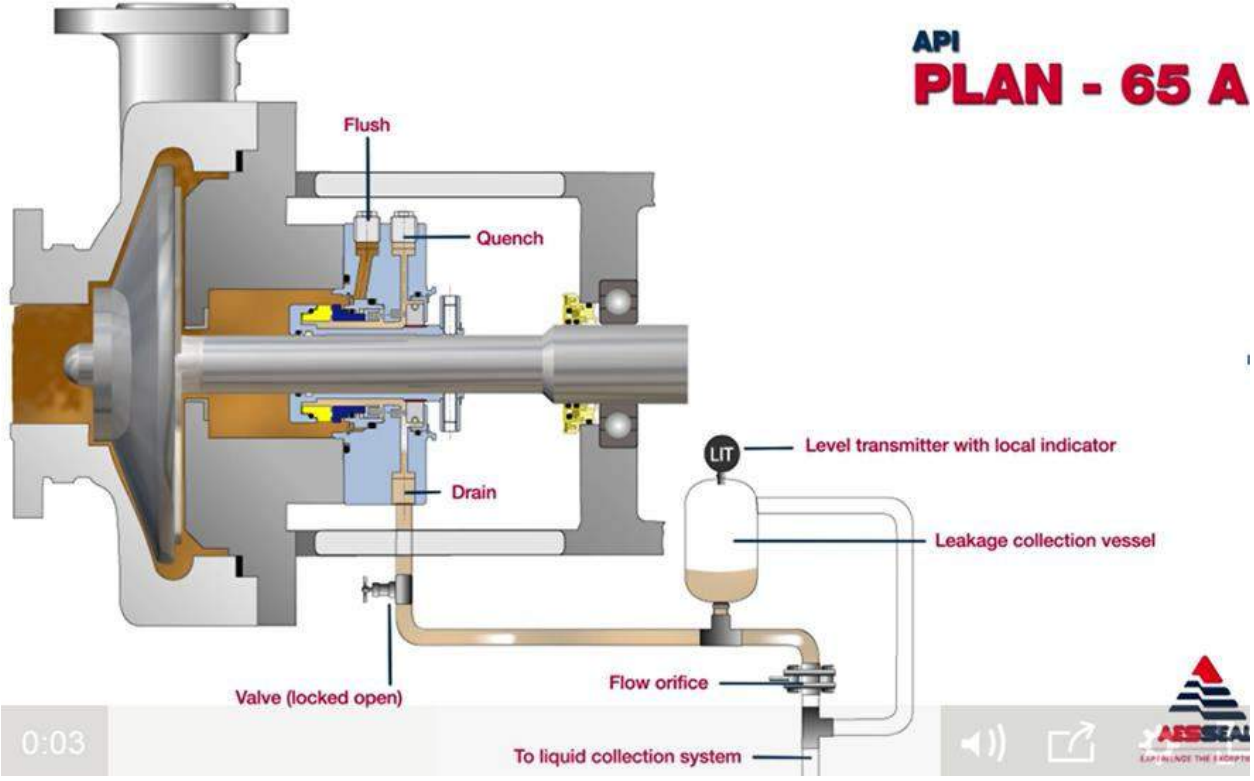
1. Normally used with single seals where the leakage is expected to be mostly liquid.
2. Piping is connected to the drain connection of the gland plate.
3. Excessive flowrates are restricted by the orifice downstream of the vessel.
4. The Level switch alarms in the event of a seal failure.

**Use**

1. in services where seal leakage is condensing.
2. Used for single seals.

**Caution**

1. Vent connection should always be plugged.
2. Orifice downstream of the level switch should be located in vertical piping leg to avoid accumulation of fluid in drain piping.
3. Shut down the pump as soon as high-level alarm is activated and attend the seal.


API
PLAN - 65 A
Flush
Quench
LIT
Level transmitter with local indicator
Drain
Leakage collection vessel
Valve (locked open)
Flow orifice
To liquid collection system
0:03
AESSEAL

## API PLAN -66 A

**Description:** Throttle bushing in seal gland restricts seal leakage in event of seal failure. Pressure increase is detected by a pressure transmitter.

**Features:**

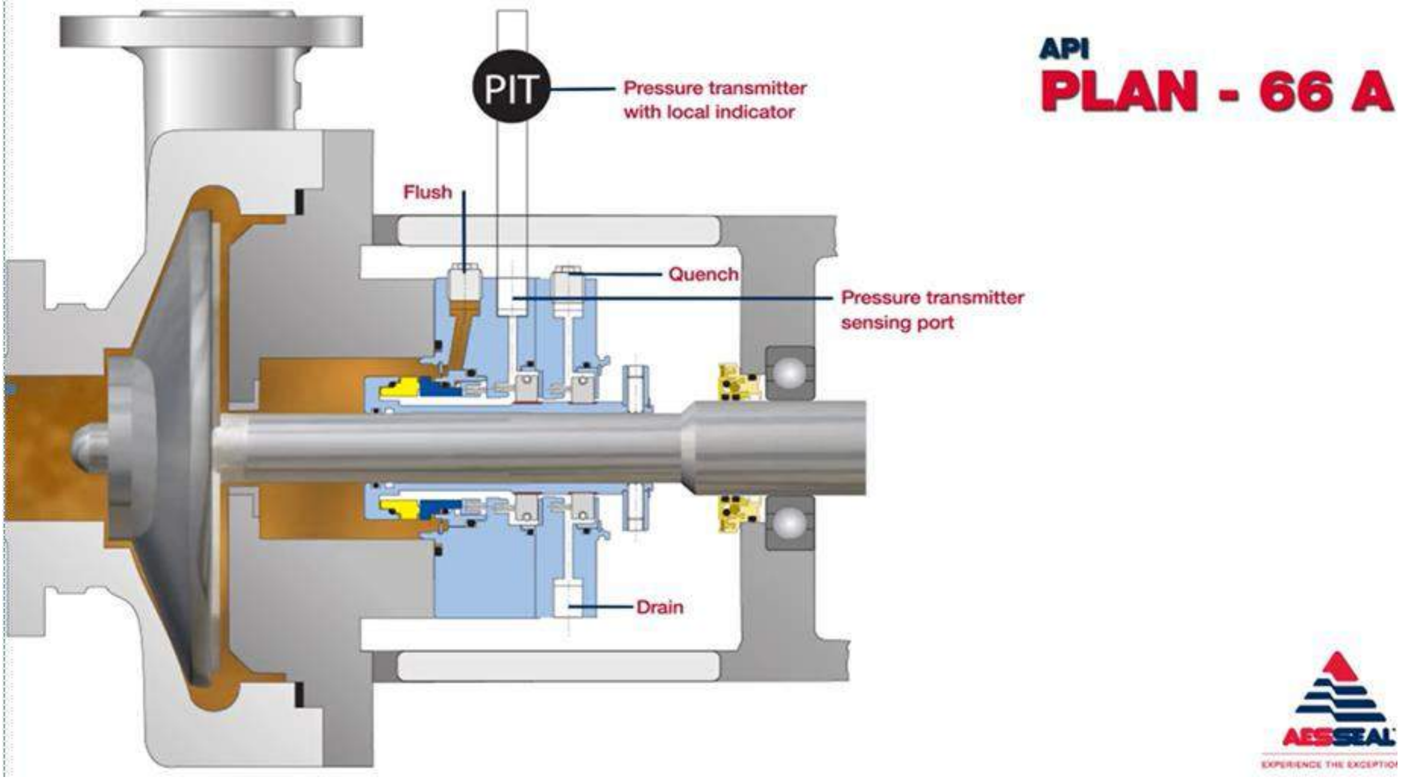
- 1. Normal leakage passes, inner restriction bush to drain.
- 2. Excess leakage is restricted by inner bush from leaving seal gland causing pressure increase, which is sensed by the pressure transmitter.
- 3. Leakage is directed to liquid recovery system or sump.

**Uses:**

- Intended for use with arrangement 1 seals where it is required to limit leakage in case of seal failure.

**Caution:**

- Drain connection must be at the bottom position.


PIT
Pressure transmitter with local indicator
API
PLAN - 66 A
Flush
Quench
Pressure transmitter sensing port
Drain
AESSEAL
EXPERIENCE THE EXCEPTION

---

## API PLAN -66 B

**Description:** Orifice plugs in drain port restricts seal leakage in event of seal failure. Pressure increase detected by pressure transmitter.

**Features:**

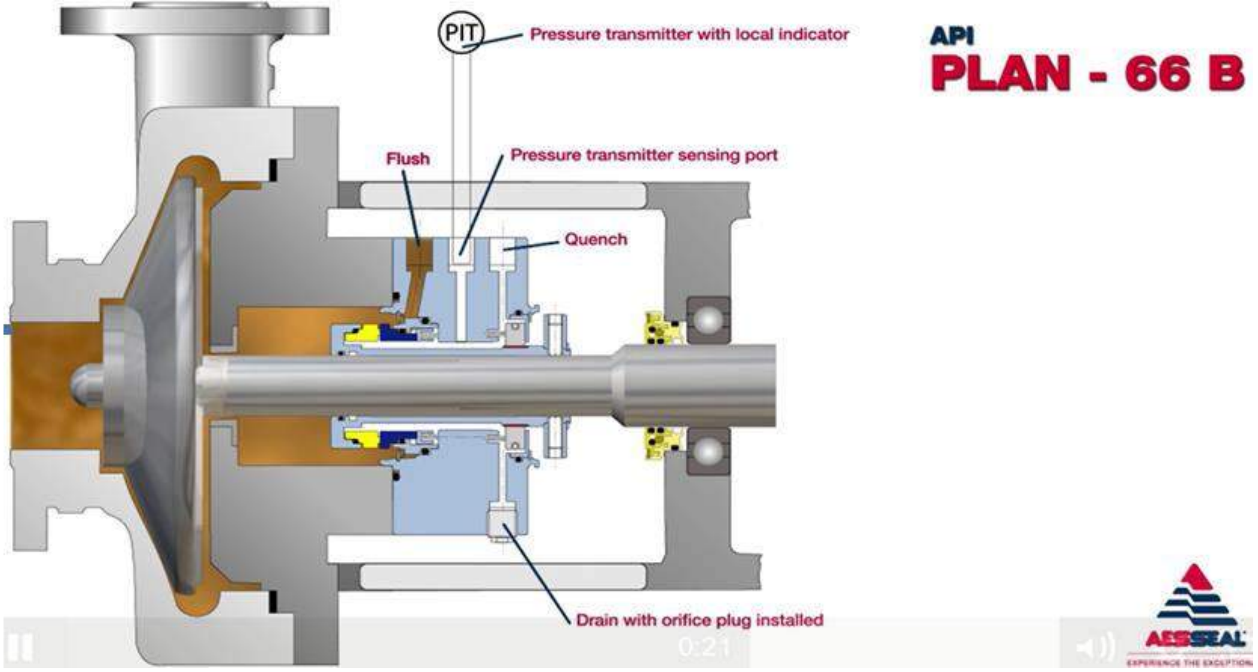
- 1. Normal leakage passes through orifice plug to drain.
- 2. Excess leakage is restricted by orifice plug from leaving seal gland causing pressure increase, which is sensed by the pressure transmitter.
- 3. Leakage is directed to liquid recovery system or sump.

**Uses:**

- Intended for use with arrangement 1 seals where it is required to limit leakage in case of seal failure.

**Caution:**

- Drain connection must be at the bottom position.


PIT
Pressure transmitter with local indicator
API
PLAN - 66 B
Flush
Pressure transmitter sensing port
Quench
Drain with orifice plug installed
0:21
AESSEAL
EXPERIENCE THE EXCEPTION

## API PLAN -71

**Description :** Plugged connections for future provision to supply a buffer gas to a dual containment seal.

**Features**

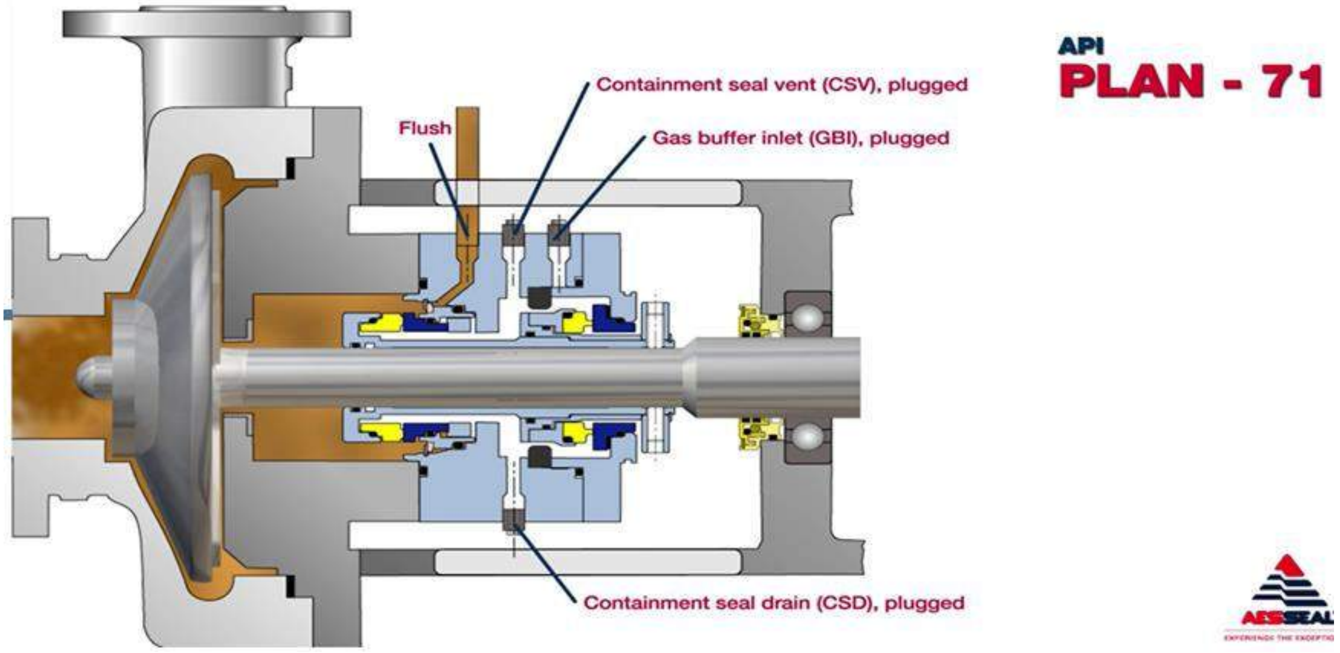
1. Vent port can be piped to use as ‘CSV’ in Plan 76.
2. Drain port can be piped to use as ‘CSD’ in Plan 75.
3. GBI port can be piped to use as in Plan 72.

**Use**

1. for future provisions for API Plans 72, 75 and 76.

**Caution**

1. Always keep the ports plugged.


API
PLAN - 71
Containment seal vent (CSV), plugged
Flush
Gas buffer inlet (GBI), plugged
Containment seal drain (CSD), plugged
AESSEAL

---

## API PLAN -72

**Description :**Buffer gas is passed through the containment seal chamber to sweep inner seal leakage away from outer seal to a collection system and / or dilute the leakage.

**Features**

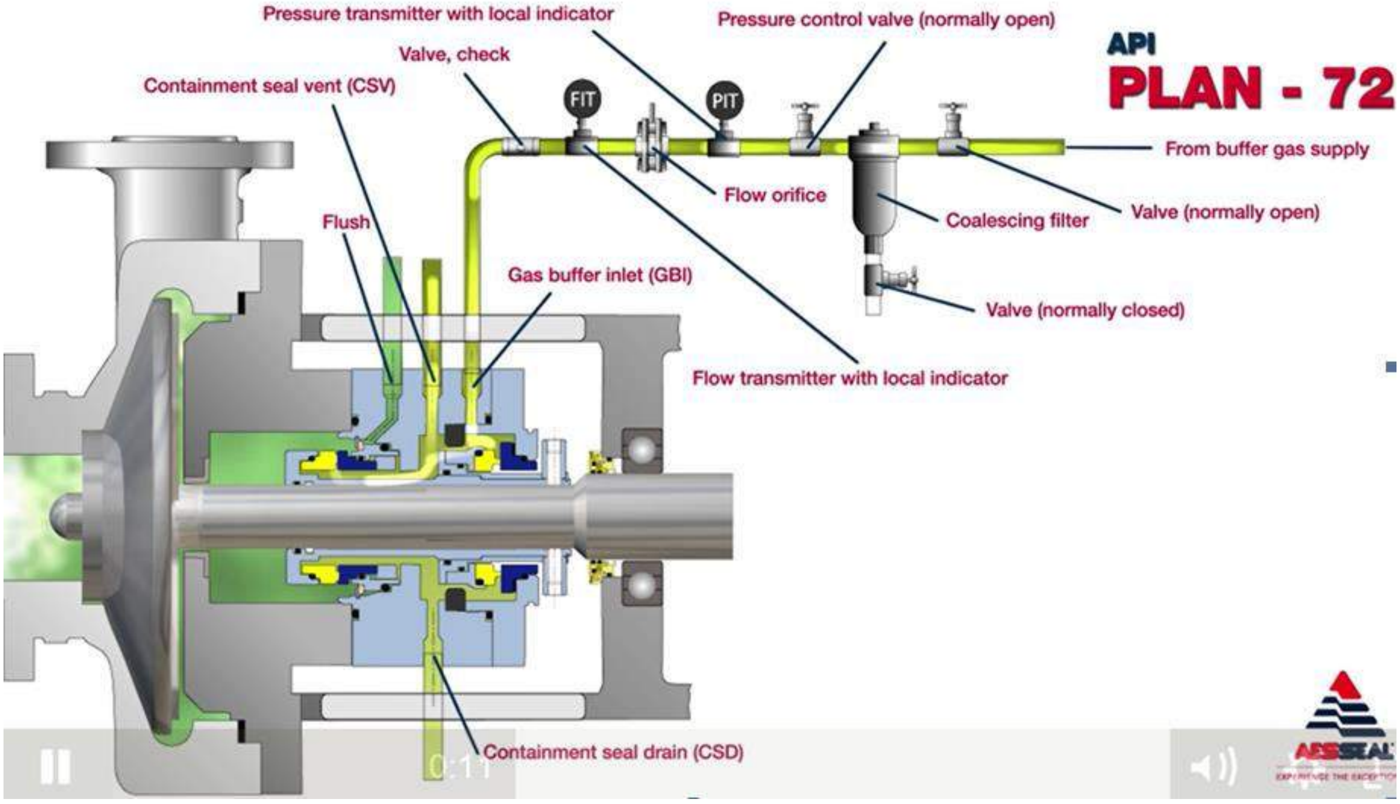
1. Used in conjunction with API Plan 75 and/or 76.
2. Nitrogen provides cooling to seal faces.
3. Nitrogen blanket reduces the explosion hazard in high vapor pressure liquids.
4. This plan is used in conjunction with Plan 75 and 76.

**Use**

1. for flashing hydrocarbons.

**Caution**

1. Always ensure that buffer gas pressure is less than seal chamber pressure.
2. Set the forward Pressure control valve at minimum 0.4 bar above flare back pressure.


Pressure transmitter with local indicator
Pressure control valve (normally open)
API
PLAN - 72
Valve, check
Containment seal vent (CSV)
FIT
PIT
From buffer gas supply
Flow orifice
Coalescing filter
Valve (normally open)
Flush
Gas buffer inlet (GBI)
Valve (normally closed)
Flow transmitter with local indicator
Containment seal drain (CSD)
0:11
AESSEAL

## API PLAN -74

**Description** Externally pressurized barrier gas supplied through a gas control system to a dual seal arrangement. An inert gas is used as a barrier gas.

### Features

1. Media leakage to atmosphere is eliminated.
2. Obtain very high reliability, as solids or other materials, which can lead to premature seal failure cannot enter the seal faces.

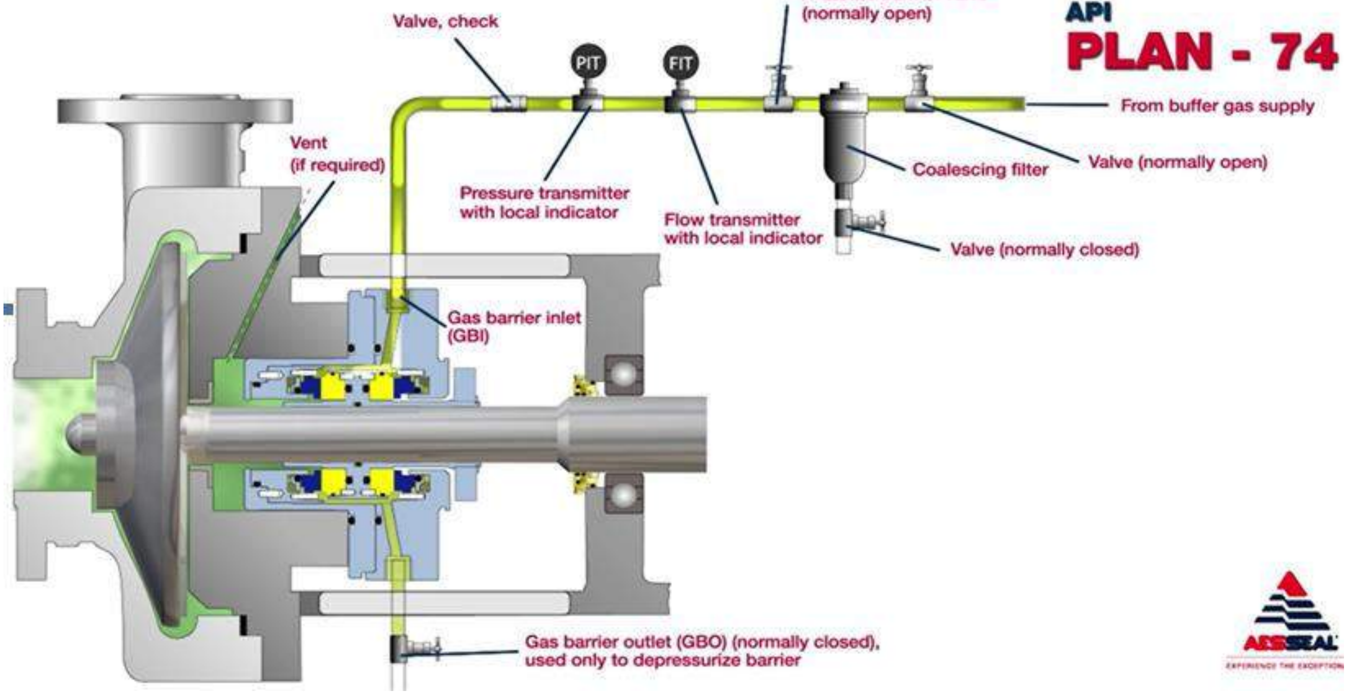
### Use

This plan is intended to be used for dual pressurized non-contacting gas seals.

1. Used in services which are not hot (within elastomer temperature limit) but which may contain toxic or hazardous material whose leakage to atmosphere cannot be tolerated.
2. In case of solids or other material present in sealing media.
3. Where process contamination is allowed but process liquid leakage to atmosphere is not allowed

### Caution

1. Always ensure barrier gas pressure is higher than seal chamber pressure.
2. causes media contamination due to high-pressure nitrogen entering the pump.
3. Pressure control valve should be set at least 1.7 bar greater than the seal chamber pressure.
4. Carefully consider the reliability of barrier pressure source, if central pressure issued.
5. Always check filter for any possible blockage.
6. Do not use for sticking or polymerizing media


Pressure control valve
(normally open)
API
PLAN - 74
Valve, check
PIT
FIT
From buffer gas supply
Vent
(if required)
Pressure transmitter
with local indicator
Flow transmitter
with local indicator
Coalescing filter
Valve (normally open)
Valve (normally closed)
Gas barrier inlet
(GBI)
Gas barrier outlet (GBO) (normally closed),
used only to depressurize barrier
AESSEAL
EXPERIENCE THE EXCEPTION

## API PLAN -75

**Description :**Leakage of condensate from inboard seal of a dual containment seal is directed to a liquid collector.

### Features

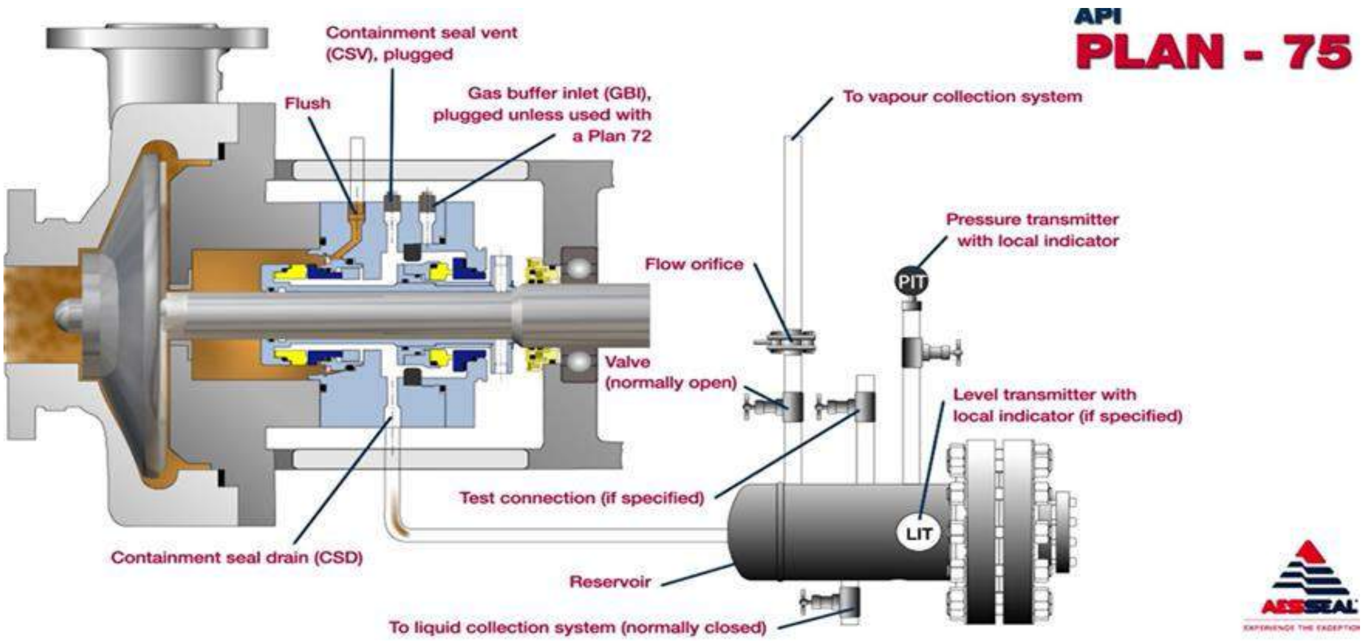
1 Can be used with Plan 72 with buffer gas or with Plan 71 without buffer gas systems.
2. Collection can be redirected to process fluid by using separate pumping device.
3. Can be used in single containment seal also.
4. Test connection is provided to check the inner seal by closing the block isolation valve while pump is in operation and noting the time / pressure build-up relationship in the collector.

### Use

1. Duties with condensing leakages.
2. Hazardous, toxic fluids.
3. May also be used for non-condensing leakages. In such cases, the collector can help in collecting condensate from the vapor recovery system.

### Caution

1. Ensure that collection system is located below the seal drain with sloping pipelines.
2. Drain port should be at bottom of containment seal to allow the leakage to flow to the collection system.
3. Collection system should always be vented releasing vapors of process liquid to vapor recovery system.
4. Valves that are installed should be accessible to operator relative to ground clearance and other obstructions.
5. A flow control orifice is required to create back pressure on collection system and to have effective condensation of vapors.
6. Pressure switch should be set at a gauge pressure of 0.7 bar.


API
PLAN - 75
Containment seal vent (CSV), plugged
Flush
Gas buffer inlet (GBI), plugged unless used with a Plan 72
To vapour collection system
Pressure transmitter with local indicator
PIT
Flow orifice
Valve (normally open)
Level transmitter with local indicator (if specified)
Test connection (if specified)
LIT
Containment seal drain (CSD)
Reservoir
To liquid collection system (normally closed)

----------------------------------------------------------------------------------------------------------------------------

## API PLAN -76

**Description** :Vapor leakages from inboard seal of dual containment seal are directed to a vapor recovery system via a vent connection.

**Features**

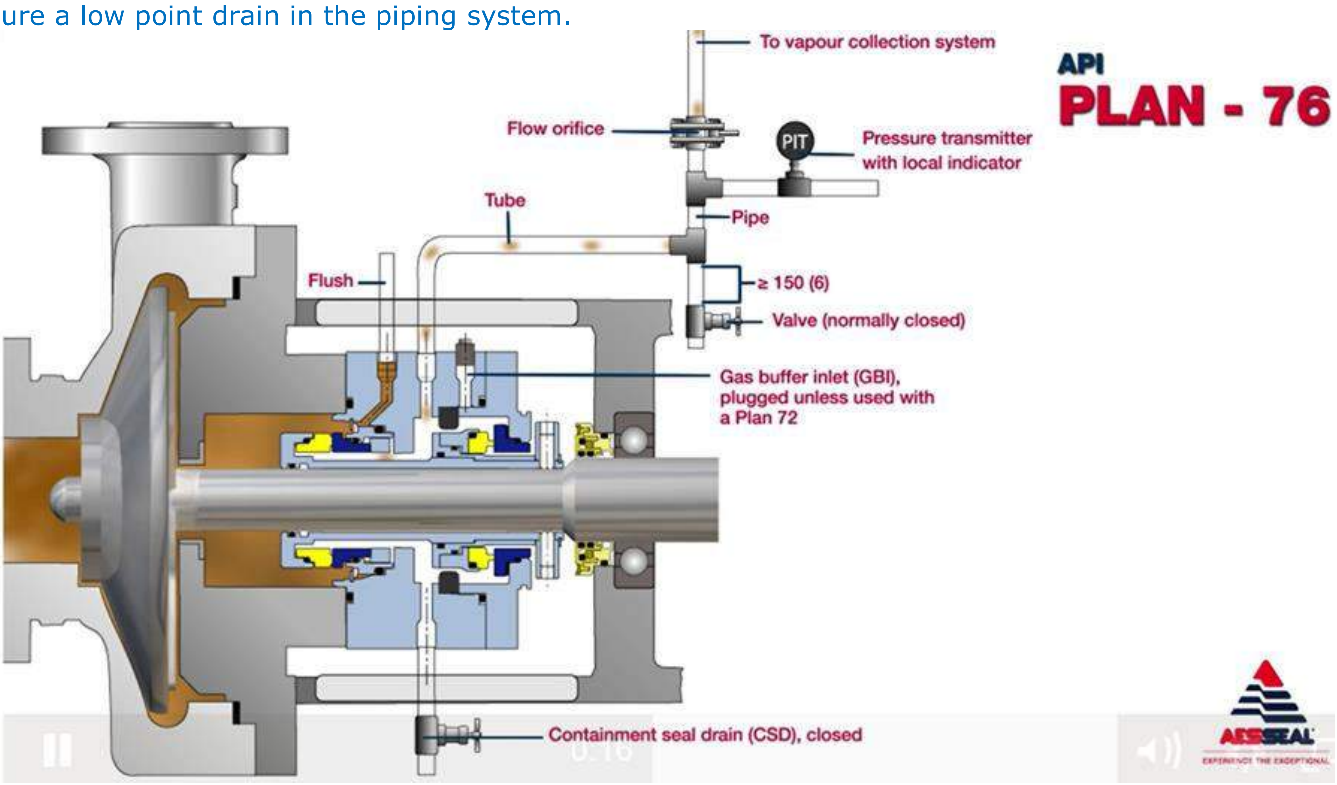
1. Can be used with Plan 72 with buffer gas or with Plan 71 without buffer gas system.
2. Vapor leakage collection ensures zero to very low process emissions from outboard containment seal.

**Use**

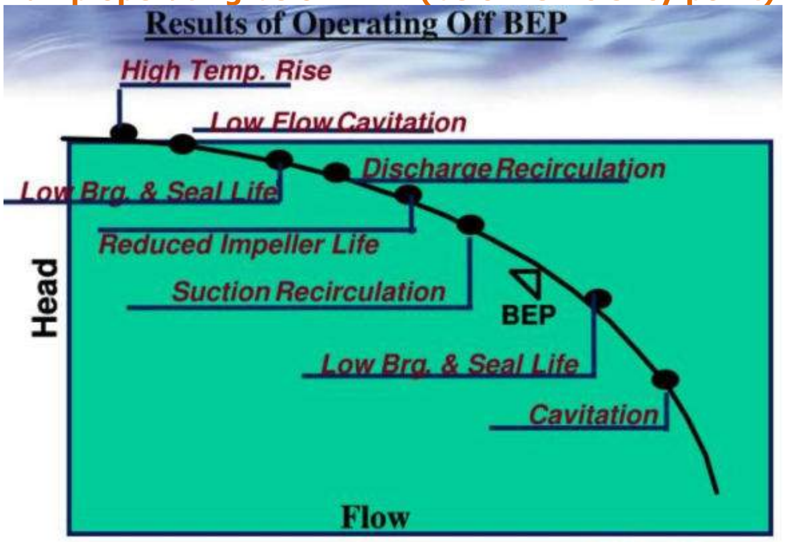
1. for high vapor pressure fluids, light hydrocarbons.
2. for hazardous or toxic media.

**Caution**

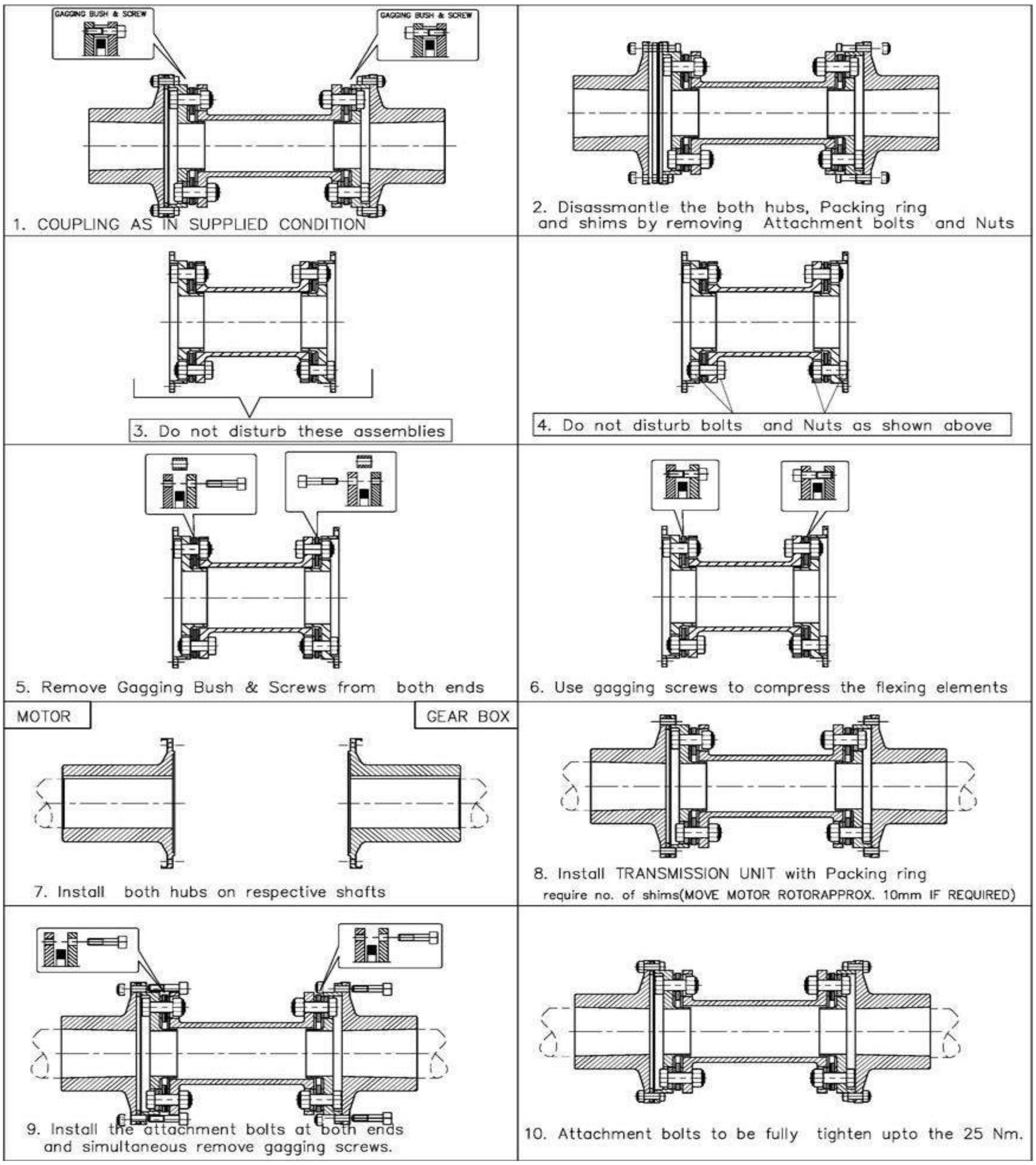
1. Do not use for condensing media.
2. Ensure continuous vent to low pressure vapor recovery or flare system.
3. Tubing shall be 1/2" (13mm) minimum diameter and shall rise continuously from the CSV connection to the piping / instrumentation harness.
4. A flow control orifice is required to generate back pressure.
5. Ensure proper support to harness piping.
6. Ensure a low point drain in the piping system.


To vapour collection system
API
PLAN - 76
Flow orifice
PIT
Pressure transmitter with local indicator
Tube
Pipe
Flush
≥ 150 (6)
Valve (normally closed)
Gas buffer inlet (GBI), plugged unless used with a Plan 72
Containment seal drain (CSD), closed

## Pump operating below BEP (below efficiency point)result :



## Installation / removal of disc coupling :



1. COUPLING AS IN SUPPLIED CONDITION

2. Disassmantle the both hubs, Packing ring and shims by removing Attachment bolts and Nuts

3. Do not disturb these assemblies

4. Do not disturb bolts and Nuts as shown above

5. Remove Gagging Bush & Screws from both ends

6. Use gagging screws to compress the flexing elements

7. Install both hubs on respective shafts

8. Install TRANSMISSION UNIT with Packing ring require no. of shims(MOVE MOTOR ROTORAPPROX. 10mm IF REQUIRED)

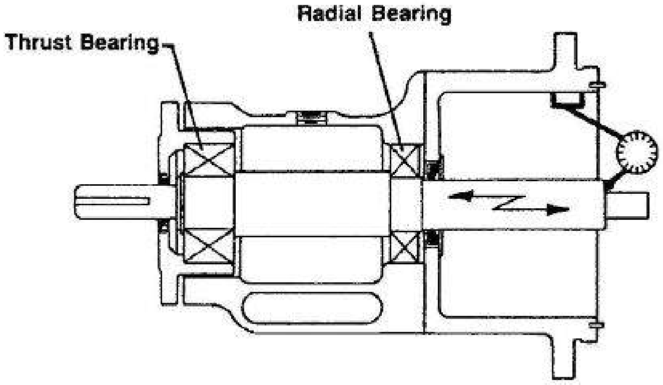
9. Install the attachment bolts at both ends and simultaneous remove gagging screws.

10. Attachment bolts to be fully tighten upto the 25 Nm.

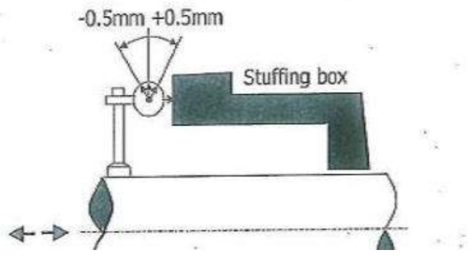
## CHECKING PUMP TOLERANCES

If mechanical seals are used, the pump must be maintained to some very strict tolerances with regard to the shaft and stuffing box. Before checking these measurements, the shaft and stuffing box should be cleaned and buffed. All burrs and sharp edges on keyways should also be removed. Every time a seal is replaced, the procedure should include checking the following shaft and stuffing box tolerances:

## MAXIMUM ENDPLAY - 0.010"

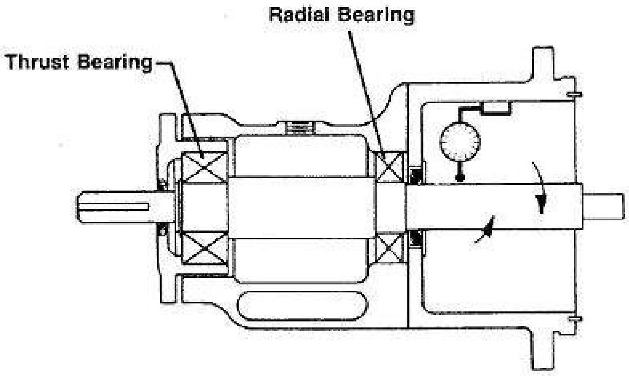

Radial Bearing
Thrust Bearing

Shaft axial movement (end play) shall be limited to that of the bearing, and is permissible only at start up.


-0.5mm +0.5mm
Stuffing box

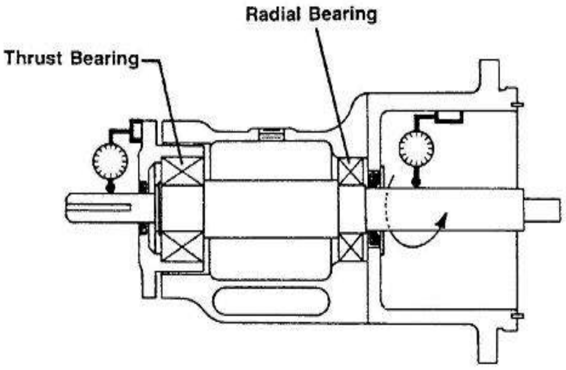
Endplay is the axial or lateral (end-to-end) movement of the shaft. A dial indicator is placed against the shaft shoulder. The shaft is tapped on both ends with a soft mallet and the results are read on the dial indicator. This reading should not exceed 0.010".

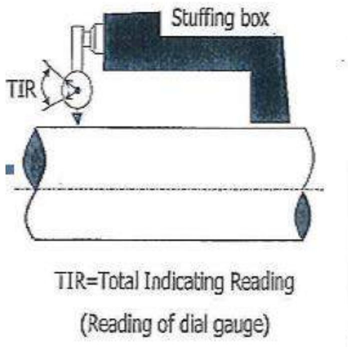
## MAXIMUM SHAFT DEFLECTION - 0.002"


Radial Bearing
Thrust Bearing

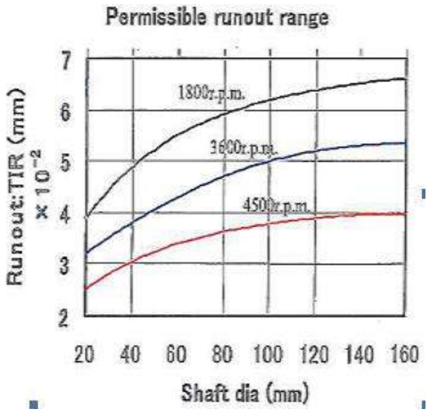
The maximum shaft deflection or whip (side-to-side) movement should not exceed 0.002". The shaft deflection is measured by placing the dial indicator as close to the stuffing box face as possible and lifting the shaft at the impeller end to check the side-to-side movement. Excessive movement is usually due to damaged bearings.

## MAXIMUM SHAFT RUNS-OUT - 0.003"


Radial Bearing
Thrust Bearing

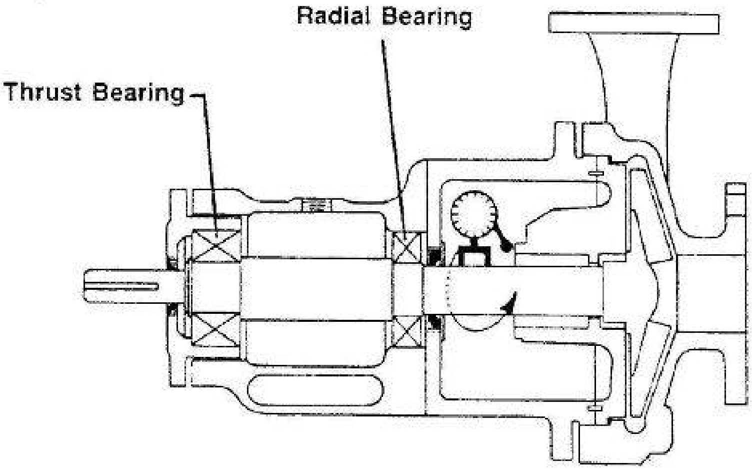

Stuffing box
TIR

TIR=Total Indicating Reading
(Reading of dial gauge)



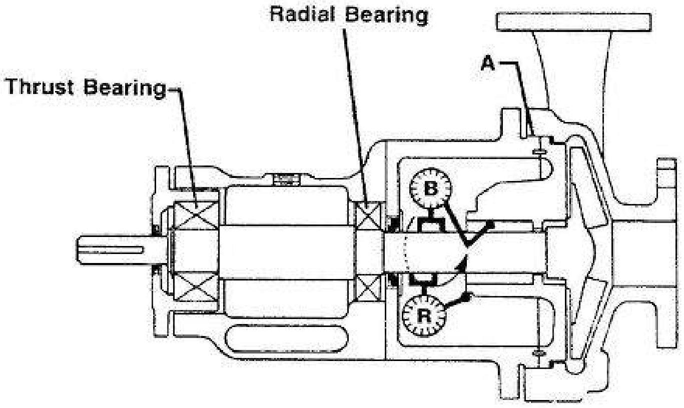
Shaft run-out is caused by the wobble of a bent shaft. Run-out should be checked by taking readings on at least two points on the shaft. First, place the dial indicator on the shaft in the area of the stuffing box face and turn the shaft. Then move the dial indicator to the coupling end of the shaft and repeat the measurement. Excessive run-out will result in bearing damage, which will cause vibration. The vibration will cause a premature seal failure.

## MAXIMUM STUFFING BOX FACE RUN-OUT - 0.005"


Radial Bearing
Thrust Bearing

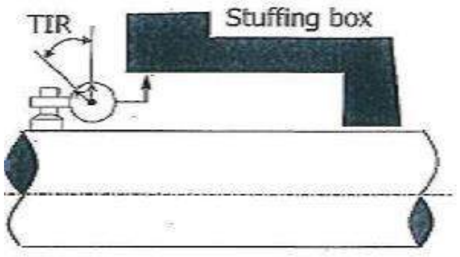
If the stuffing box face is not perpendicular to the shaft, the seal insert will not mate squarely with the rotating seal. This misalignment will cause the seal to wobble as it spins, again resulting in premature seal failure. This is measured by attaching the dial indicator to the shaft with the stuffing box bolted in place. The instrument is then placed against the face of the stuffing box and the run-out is measured as the shaft is turned.

**MAXIMUM STUFFING BOX ECCENTRICITY - 0.005"**

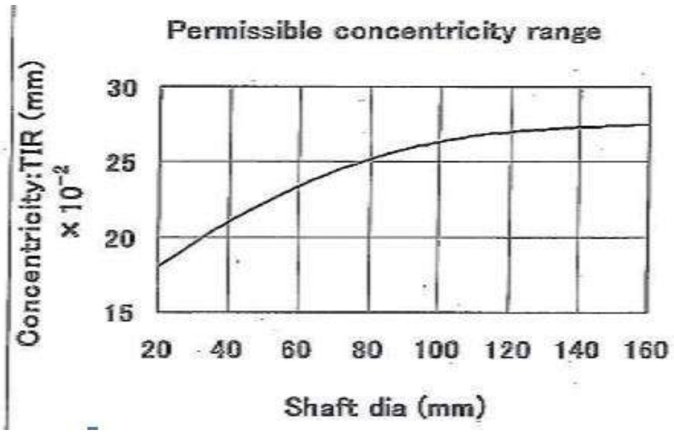


When the stuffing box is concentric to the shaft, the distance from the outside of the shaft to the inside of the stuffing box is the same all the way around the stuffing box. If it is closer on one side than the other , it is said to be eccentric to the shaft. This condition places the seal faces off-center and alters the hydraulic loading of the seal faces which will reduce the seal life. This is measured by attaching the dial indicator to the shaft, as with stuffing box face run-out, and measuring either the bore (inside) and register (outside) of the stuffing box.

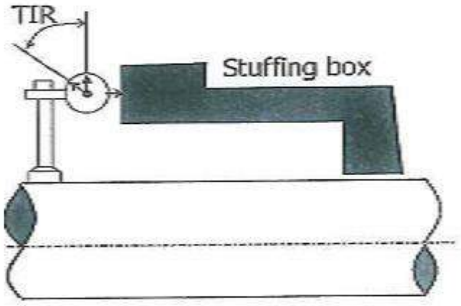
## CONCENTRICITY CHECK



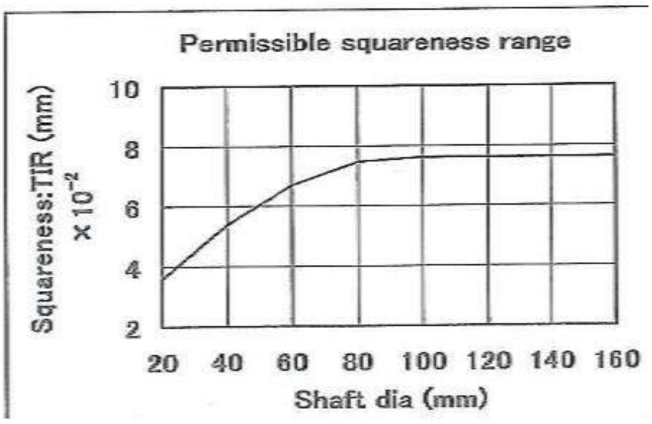
TIR=Total Indicating Reading
(Reading of dial gauge)



## SQUARENESS CHECK



TIR=Total Indicating Reading
(Reading of dial gauge)



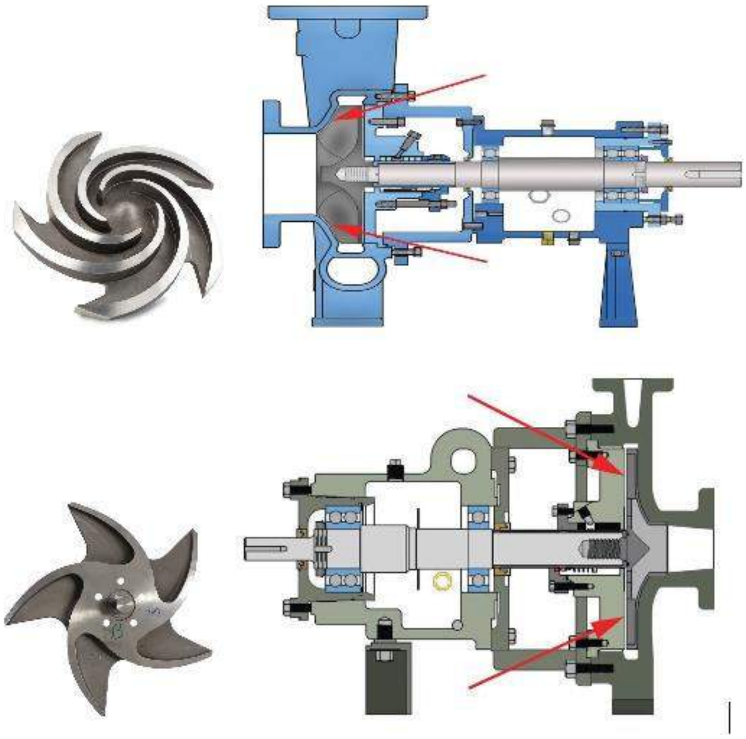
## PUMP IMPELLER ADJUSTMENT

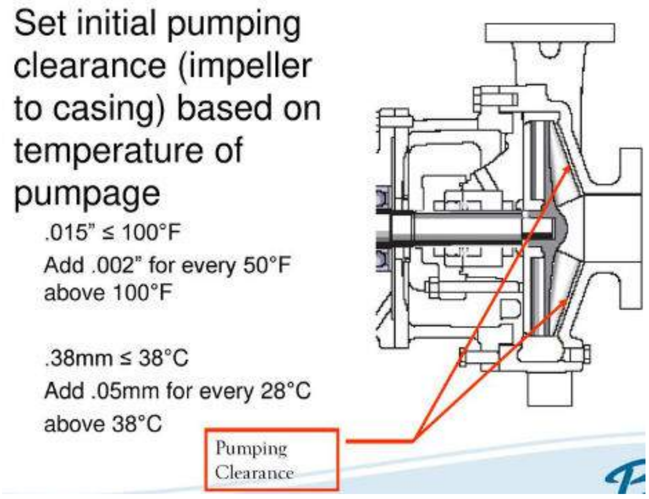
Pumps should be adjusted to operate with the Impeller having minimum axial clearance with the front casing liner (Throat bush or Cover Plate Liner). This is most important with High Efficiency Impellers. Adjustment of Impeller front-end clearance is carried out as follows:

(a) Rotate the Shaft clockwise (from the drive end) by hand, and move the Bearing Assembly forward (towards the pump intake) by adjusting the rear nut on the ADJUSTING SCREW until the Impeller rubs on the front Liner.

(b) Unscrew the rear nut by one sixth of a turn, and move the Bearing assembly back by adjustment of the front nut on the adjusting screw until the plug on the bearing assembly contacts the rear nut. Fully tighten the front nut to secure the Bearing Assembly in position.

(c) Ensure that the Shaft can now rotate freely without contact of the Impeller with the front Liner. If contact occurs, repeat step.





Set initial pumping clearance (impeller to casing) based on temperature of pumpage

.015” ≤ 100°F

Add .002” for every 50°F above 100°F

.38mm ≤ 38°C

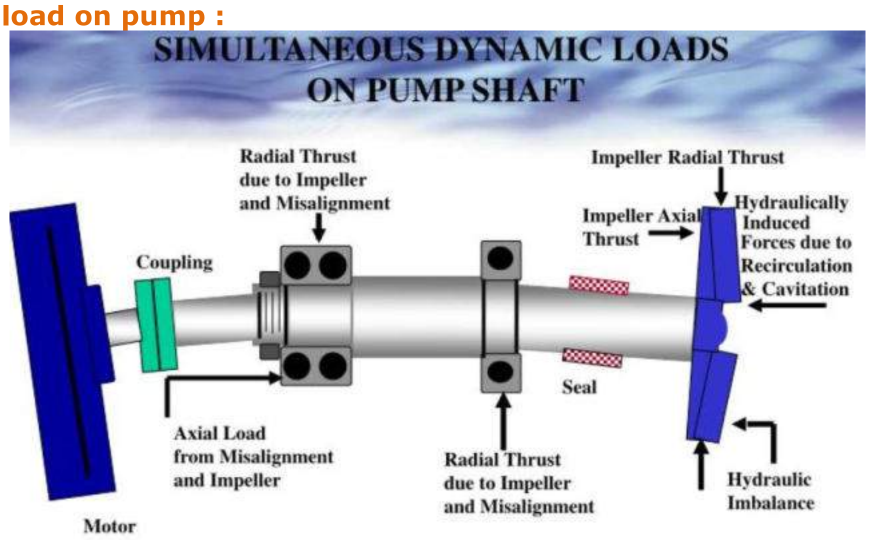
Add .05mm for every 28°C above 38°C

Pumping Clearance

**Impeller Setting can be done by dial gauge or with feeler gauge**

A typical setting technique is to tighten the nuts on the back of the pump coupling end until the impeller rubs against the volute then back off the nuts the proper clearance, and turn the jack bolts (located between the adjusting nuts) inward until the shaft assembly bottoms against the adjusting nuts.

**Dynamic load on pump :**

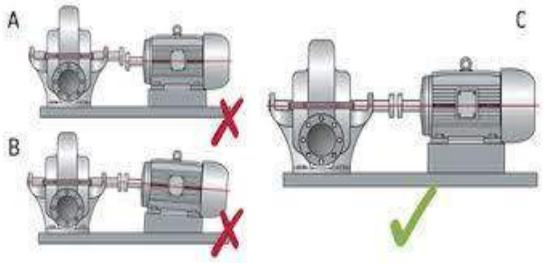


SIMULTANEOUS DYNAMIC LOADS ON PUMP SHAFT
Radial Thrust due to Impeller and Misalignment
Impeller Radial Thrust
Impeller Axial Thrust
Hydraulically Induced Forces due to Recirculation & Cavitation
Coupling
Seal
Axial Load from Misalignment and Impeller
Radial Thrust due to Impeller and Misalignment
Hydraulic Imbalance
Motor

**ALIGNMENT :**

**What is shaft alignment?**

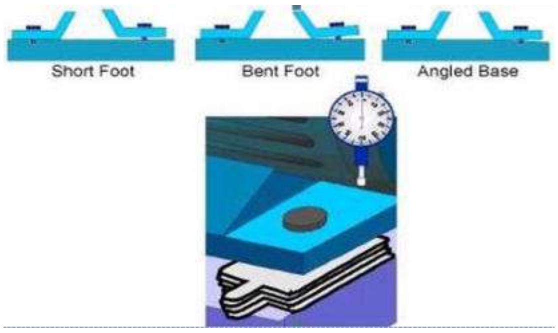
Shaft alignment is the process to align two or more shafts with each other within a tolerated margin to achieve collinearity between the shafts axis when in normal operation.



**Things to consider prior to starting the alignment:**

- **Shaft run-out** - Make sure that run out at the shaft as well as coupling is less than 0.05 mm on both the machines. Piping stress /forces -Ensure that connected pipes are well fitted, supported and sufficiently flexible, so that no more than 0.076 mm in V & H movement occur at the flexible coupling when last flange is tightened.
- **Foundation**- Rule of thumb: concrete weight = x 3 rotating machine & x 5 Reciprocating
- **Soft foot** -One or more than one of the equipment feet may not make good contact at the frame.
  - For machines already in operation it is necessary to ensure that causes of soft foot are not external i.e. piping load or cable pull. For new installation, it is recommended to check the soft foot before piping and cable connection.

## How detect soft foot.



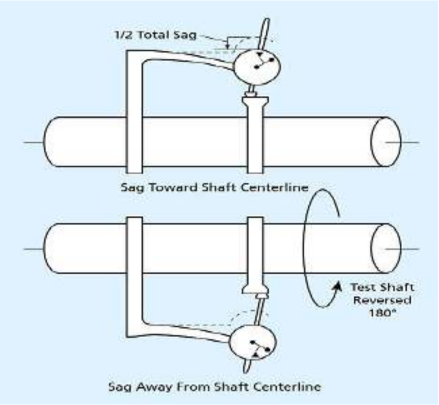
- ○ Set the machine in place, but do not tighten the hold-down nuts
- ○ Attempt to pass a thin filler gauge – check for gap
- ○ Tighten all hold-down nuts on the machine to be aligned
- ○ Secure a dial indicator holder on one foot
- ○ Set the dial indicator to zero (0)
- ○ Completely loosen the hold-down nut(s) on that foot only. Watch the dial indicator for foot movement during the loosening , Loose all bolts one by one & observe the dial movement, if is not exceeding 0.05mm, no correction is required & no soft foot exists.

## Bar sag

How to identify and consider alignment clamp sag?

Alignment clamp sag-

- ▪ When dial is at 12 o'clock position, the clamp bends towards the coupling
- ▪ When dial is at 6 o'clock position, the clamp bends away from the coupling



- ○ With bracket on top of the bar stock the indicator is set to zero , Rotate the assembly by 180 deg. So that the indicator reads directly on the bottom of the bar stock
- ○ Sag=TIR/2 (sag value will be negative)
- ○ Add twice the amount of true sag to the bottom reading and correct the side readings by adding the amount of sag

Taking dial gauge reading for calculation of "TIR" (Total indicator reading/ run out) is not an easy Job. When it comes to practical many EXPERTS get confused. In order to understand alignment /TIR it is essential to know about dial gauge and its working.

A dial gauge or indicator consists of components such as bezel, indicating pointers, tool post and clamp, magnetic tool holder and sensor button. Dial indicators are available in many physical sizes and ranges. For most alignment applications the smaller sized indicators should be used to reduce indicator bar sag.

**Backlash Error** Check the indicator for backlash error. Press the sensor gently and then release and note down the dial gauge reading, Repeat this process two three times. Every time dial gauge reading should be same. If readings differ then change the dial gauge.

**SAG =dial reading/2**

Dial indicator bar sag describes a bending of the hardware used to support a dial indicator or other part which spans the coupling. The bending action occurs as a result of gravity and cannot be totally eliminated in almost all cases of alignment. Numerous attempts have been made by fixture manufacturers to minimize the amount of sag that occurs; however, none have been successful in "eliminating" it for all alignment situations, only minimizing it.

### EFFECT OF SAG ON THE ALIGNMENT PROCESS

Indicator bar sag occurs for all types of alignment readings; however, sag affects only one particular type of reading in nearly all alignment tasks. That type of reading is the offset reading taken in the vertical plane. Except in rare situations, sag has negligible effect on offset readings taken in the horizontal plane and on conventional angularity type readings taken on the face of a coupling.

## What are the pre- alignment checks to be carried out in aligning rotating machinery?

The pre- alignment checks involved in aligning rotating machinery are:-

A. Check the machine is properly secured to foundation.
B. Check for excessive run- out conditions i.e. Eccentric coupling bore, Bent Shaft.
C. Machine to base plate interface problems i.e. soft foot.
D. Ensure that no piping loads / stress are coming on the machine and flange studs should be free -

0.07/0.08 mm stud off-center allow.
E . Check physical condition of coupling, shims, hub, shaft..etc
F . check dial gauge / alignment kit calibrated , measuring tool ok or not

- **What soft foot is as indicated in pre-alignment checks?**

When rotating machinery is set in place on its base frame/ sole plate, one or more than one of the ‘feet’ may not make good contact at the ‘foot points’ on the frame. This is due to bowed/ warped frames, improper machining of feet.

- **What is Blue matching with reference to the alignment of rotating machinery?**

It is a type of level / surface –flatness check. In this method blue colour (Blue mixed with oil) is applied with the help of brush on to surface of a glass of suitable size. The glass with the painted surface pointing towards the mounting pad is place on to the mounting pad and is rotated with little pressure. Now the glass is removed from the mounting pad. The surface of mounting pad which is slightly up is now clearly visible as the blue colour stick on these portions. Now these coloured surfaces shall be flattened by using rotating disc. Repeat the above procedure till 80% of the mounting pad surface gets coloured.

- **What are the Tools required for measuring the shaft centre line during alignment?**

A. Straight edge. B. Feeler Gauge C. Taper Gauge. D. Measuring Tape & Ruler. E. Alignment Bracket. F. Vernier caliper. G. Dial Indicator.

- **How the Dial Indicator reading is interpreted? Mention method of measurement by Dial indicator?**

The inward movement is indicated by clockwise movement of indicator or in (+) direction. The outward movement is indicated by anti-clockwise movement or in (–) direction.

**Different measurement methods are:-**

A. Vertical Move : the vertical offset of 0.02mm of a shaft with respect to the other shaft will be displayed.
B. Sweep Reading : Sweeping reading is obtained by zeroing the dial at the top position on the coupling to be indicated. Slowly rotate the shaft so that the dial indicator is rotated by 360 degree in 90 degree increment. Obtain reading at top (T), bottom (B), right (R) and left (L).
C. Horizontal move : the alignment of two shaft having 0.02mm vertical offset and 0.02mm horizontal offset will look alike.

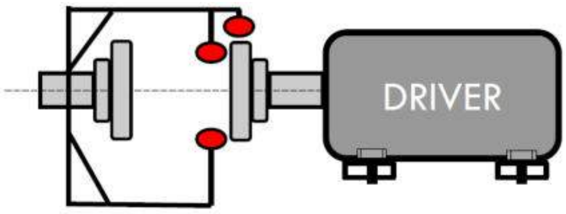
- **What are the different alignment techniques adopted for aligning rotating machinery and alignment tolerance?**

Following alignment techniques are adopted for aligning rotating machinery.
A. Straight edge & feeler gauge Method.
B. Shaft alignment using dial indicator.
Face-rim method. - Two indicator method, Three indicator method, Reverse indicator method. & Face-Face- Distance method.
C. Laser Alignment method.
D . Graphical method

**Alignment tolerance - 0.05mm in all respect.**

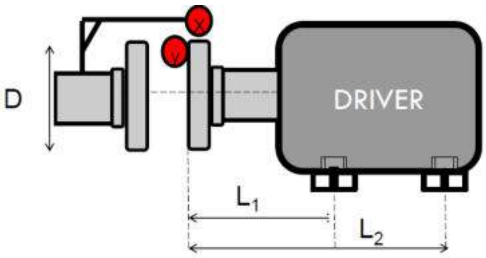
**Shaft Alignment is a purely mathematical term that can be identified and corrected using one of the following methods:**

**Rim and Face**



**When it is preferred?** Distance between the two adjacent shaft ends is less than one-half the coupling diameter. Face reading to be taken as much as possible near outside diameter.

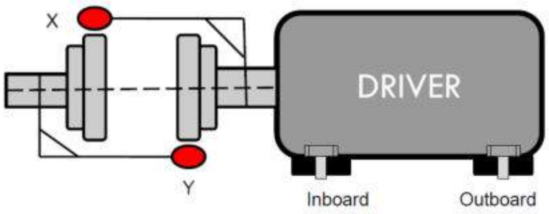
  - Axial shaft movement during face reading measurements can cause false readings. In that case use two dial indicators mounted 180º apart. When using this setup, set dial indicator at 0º and 180º position and zero indicators. Dial indicator at 0 should be tagged prime dial indicator.



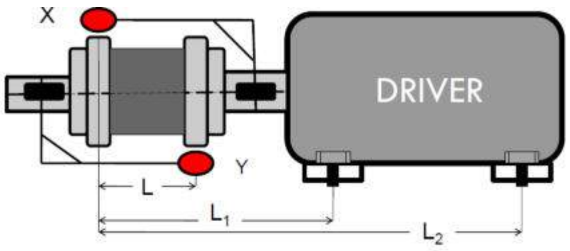
- D= Diameter on which the axial dial is moving. This will be approximately equal to coupling diameter in most of the cases.
- $L_1$= Distance at front leg from motor coupling.

- $L_2$= Distance at back leg from motor coupling.
- Y is the axial dial reading
- X is the radial dial reading
- Shimming req. at front/back leg= ($L_1$or $L_2$ x Y/D)+(X/2)

### Reverse indicator

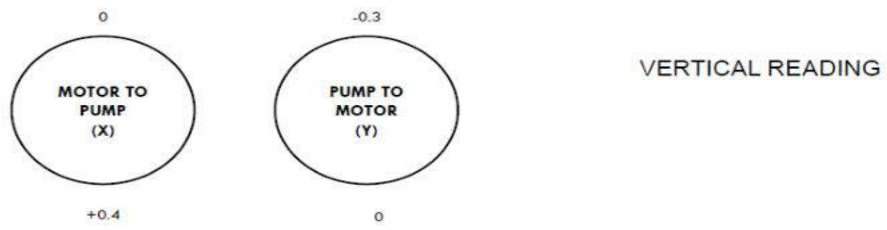

X
Y
DRIVER
Inboard
Outboard

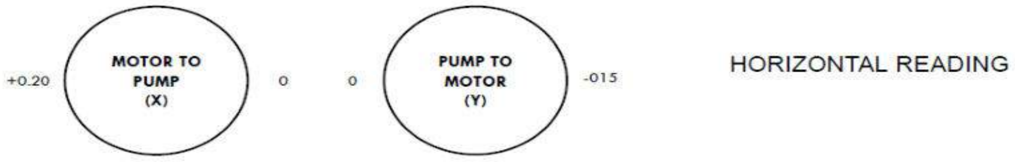
**When it is preferred?** The “Reverse indicator method” is the preferred when the distance between the adjacent shaft ends is greater than one-half the coupling diameter.


X
Y
DRIVER
L
$L_1$
$L_2$

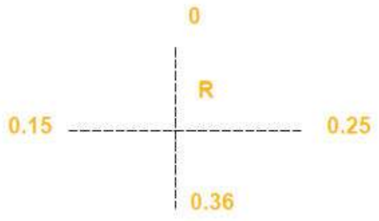
- L=Distance between the dial indicators pointer.
- $L_1$= Distance at front leg from the fixed machine coupling.
- $L_2$= Distance at back leg from the fixed machine coupling.
- X is the dial reading on the fixed machine
- Y is the dial reading on the movable machine

**Example :**


0
MOTOR TO PUMP (X)
+0.4
-0.3
PUMP TO MOTOR (Y)
0
VERTICAL READING


+0.20
MOTOR TO PUMP (X)
0
0
PUMP TO MOTOR (Y)
-015
HORIZONTAL READING

- Required shim at front leg of motor
- $Z_1= \{(L_1/L) \text{ X } (X-Y)/2\} - \{Y/2\}$
  $= \{ (100/50) \text{ X } (0.4-(-0.3)/2\} - \{-0.3/2\}$
  $= 0.85$
- Required shim at rear leg of motor
- $Z_2= \{(L_2/L) \text{ X } (X-Y)/2\} - \{Y/2\}$
  $= \{ (150/50) \text{ X } (0.4-(-0.3)/2\} - \{-0.3/2\}$
  $= 1.25$
  $+^{ve}$ sine means add shim to respective feet
- For horizontal same repetition and to be shift by jack bolt according
- Dial pointer should prefer be kept on the machine to be shimmed.
- The sum total of both side readings should be same as sum total of top bottom readings. In actual practice, **we can allow a difference of about 15%. This rule is called validity rule**.


0
R
0.15
0.25
0.36

Sum total of side readings= 0.15+0.25=0.40
Sum total of top bottom readings=0.00+0.36=0.36
Difference = 0.40-0.36=0.04
Difference should be less than 15%
15% of 0.40=0.06
Thus difference is less than 15%

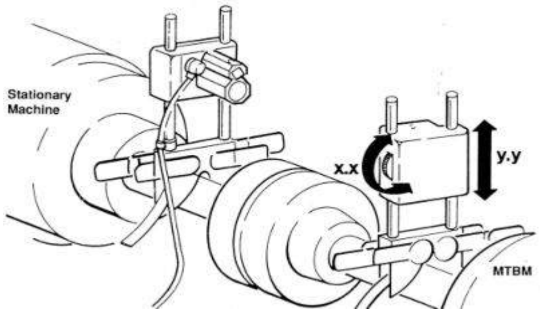
## Graphical

### When it is preferred?

- The Graphical method is the preferred when the distance between the adjacent shaft ends is greater than one-half the coupling diameter
- Long distance between feet. In other words, long rotor shaft.
- Thermal growth of the equipment.
  - Choose a graph scale large enough for provide sufficient accuracy when all calculations are completed. Log out physical dimensions of the machine train and show the collected data on the graph for completeness.
  - On the graph show the location of the machine feet, the dial indicator sweep plane and power transmission points. Note that the power transmission point do not coincide with the sweep part of dial indicators.
  - When actually plotting the vertical offsets, start with the stationary set first. Remember that the data collected represents twice the actual difference between the shaft centreline. A positive result is plotted above the line representing the stationary machine centreline. When plotting the movable machine readings a rule of thumb is that opposite signs are plotted on the same side of the stationary machine centreline on the graph.

## Laser

The laser is detected or intercepted by position sensing device. The center of energy of the laser spot is detected and converted to an electrical signal proportional to its location on the surface of the target. This signal is converted into a calibrated reading using a variety of hand held devices or computer interfaces for use with software.



## TO CALCULATE HOT ALIGNMENT READING:

### To calculate thermal expansion or contraction,

Multiply original length (generally distance from machine shaft centerline to top of baseplate or soleplate) time's expansion coefficient (0.0000067 for steel) times temperature change in degrees Fahrenheit. (Expansion coefficient is 0.000012 for steel and temperature change in degrees Celsius.)
Δ L (change in length) = L (length) x 0.0000067 x Δ T (change in temp. °F)
Δ L (change in length) = L (length) x 0.000012 x Δ T (change in temp. °C)
NOTE: Δ L and L in same units.

- **WHAT IS ANGULAR SOFT FOOT?**

Angular Soft Foot is a condition that occurs when a gap under a motor's foot is "non-parallel" to the mounting base. Because of this gap, the foot, when tightened, is forced to seat itself to whatever angle allows it to make total surface contact. As a result of this seating, stresses are created in the motor's foot that transfers through the motor "leg" and into the housing.

- **WHAT IS THE DIFFERENCE BETWEEN SOFT FOOT AND ANGULAR SOFT FOOT?**

The first step during an alignment is to check the motor's feet for gaps. Each foot is checked above and below the shim pack with feeler gages to determine if the gap between the foot and base is parallel. A parallel gap indicates regular Soft Foot. A non-parallel, irregular gap means Angular Soft Foot is present.

- **WHY IS ANGULAR SOFT FOOT A PROBLEM?**

If a motor's foot is not parallel to the base when the hold-down bolts are tightened, then the motor's housing will become twisted. This additional stress distorts the bearings and shaft. In order to alleviate this stress, all feet of the motor must sit parallel and have complete surface contact to the base. A motor that is accurately aligned and relieved of external stresses, will run smoother with less vibration, and will be more likely to attain optimum life expectancy.

- **WHAT IS A COMMON CHARACTERISTIC OF ANGULAR SOFT FOOT?**

Another hint that Angular Soft Foot may be present is when a motor seems to move or "walk" horizontally whenever the hold-down bolts are loosened or tightened during an alignment. Usually, a maintenance guys can finesse the motor into the proper alignment just by re-tightening the hold-down bolts in a particular pattern. What this individual may not realize is that the motor is "walking" because a foot is being forced to bend to make total surface contact to the mounting base. This will cause internal twisting and high vibration of the motor.

- **HOW HAS ANGULAR SOFT FOOT BEEN CORRECTED IN THE PAST?**

Typically, the most common method is to “step shim” the irregular gap by stacking very thin graduated shims. Unfortunately, even if the “step shim” is properly fitted, any horizontal adjustment to the motor during alignment can change the gap to be shimmed, making the “step shim” worthless. Also, if after startup any one of the individual “steps” in the shim happens to slip out of place, a “domino effect” may occur causing the other shims to move. However, Soft Shoe with its unique properties, cold flows into angular gaps allowing for complete surface contact between a motor's foot and base. Two other types of correction are re-machining the motor's foot or base, or pouring epoxy onto the base.

## BEARINGS

**Three basic types of bearings are used in most pumps. They are the ball, roller and plain bearing.**

### BALL BEARINGS

The pump ball bearings normally used are designed to class ABEC 1. **ABEC is an abbreviation for The American Bearing Engineers Committee**. There are five classes of ABEC: 1, 3, 5, 7 & 9.

The higher the class the tighter the tolerance of manufacture.

SKF recommends the ISO Standard 286 bearing fit. The shaft fit recommended is the k5 for 20 to 100mm bores and m5 for 100 to 140 mm bores, and the housing fit is the J7.

There are four classes of internal clearance for anti-friction ball bearings:

C-0 Regular
C-2 Snug (Comfortable)
C-3 Loose
C-4 Extra loose

**Most pump bearings have loose C-3 internal clearances**. This is the recommendation of the API pump standard. The ball bearings found in pumps are the single-row and double-row ball bearing and the angular-contact thrust bearing.

The ID dimension difference from one bearing to the next bearing varies by 0.200". The OD dimension wil vary by 0.200" to 0.400 from one size bearing to the next size.

Ball bearings are best removed with a bearing puller or an arbor press. Do not beat bearings off with a hammer or shaft damage may occur. Bearings are best installed by heating to approximately 80-100 C of and then placing them on the shaft. To heat the bearing, use a dry oven or an induction bearing heater with a demagnetizer. It is acceptable to press bearings on to a shaft. Do not install bearings with a hammer. The ball bearing will fit to the revolving pump shaft from about 0.0001 to 0.0005 tight.

All bearings should be tight to the shaft. If the bearing is shrunk onto a shaft the clearance will be manage /removed from inside the bearing housing otherwise excessive heat will be generated during operation, causing the bearing to fail. Angular contact bearings should be installed back to back.

Balls bearings should slide into the rotating housing with clearance about 0.001" on the OD. Do not install the OD tight as it will remove the internal clearance in the bearing. Repair the bearing housing when it is 0.002" over maximum.

The axial float for an installed pump shaft with ball bearings should be 0.002 to 0.004 of an inch. This clearance is installed so that thermal expansion in the bearing and/or the housing will not distort the bearings. Always change bearings during each overhaul.

### ROLLER BEARINGS

Rollers bearings- both tapered and straight are used on some slower speed pumps they are much more forgiving and rugged than ball bearings. The straight or cylindrical bearing has more clearance than a ball bearing. The inner race is shrunk on to the shaft and the outer race is a slip-fit into the housing.

The tapered roller bearing has its internal clearance determined by shimming during assembly in the pump. Most pump applications will have 0.002" to 0.004" float in the bearings. The inner race of a tapered roller bearing is shrunk on the shaft.

A slip fit of 0.001" is used on cups that must move during shimming. Larger bearings over 10 inch OD may have up to 0.002" clearance.

It is clear that the cups have been spinning in the housing or the clearance is over 0.003" for cups under 8 inches in diameter and 0.005" for larger cups sleeve the housing.

### BABBITT JOURNAL BEARINGS

Babbitt sleeve bearings are used in many high performance pumps. Most pumps with sleeve bearings operate at 3600 RPM or higher. Babbitt bearings were developed by Sir Isaac Babbitt in 1839. **The composition typically used is 89% tin, 8% antimony and 3% copper**. They offer low friction, easy lubrication and high load carrying capability. The fatigue life and load carrying capability goes up as the Babbitt thickness goes down. However, the ability of the bearing to digest fine particles in the oil decreases as the Babbitt gets thinner. All Babbitt bearings, both thin and thick shells, should be tightness is often referred to as "**crush**". The crush causes the bearing shells to go round and makes sure that the split line of the bearing shells do not close towards the shaft and cut off the oil flow. **To measure this crush** we place a shim of about 0.005 between the bearing housing halves at the split line. A piece of plastic gauge is then placed on top of the bearing shell between together tightly and then disassembled. The plastic gauge should read 0.004" to 0.005" clearance, the same as the shims at the split/line. Crushes up to 0.002" tight and 0.0005" loose are acceptable but are slightly out of the preferred tolerance.

Examples of different crushes and the recommend repair action are:

- 0.0005 Loose to 0.003 Loose - Lap the split lines.

- Over 0.003 loose - grind split lines and rebore housing.
- Over 0.002 tight - home or rebore housing.

Placing a shim on top of the bearing shell to force the bearing to crush can be performed as a short term filed emergency repair, but is generally unacceptable as a shop repair practice.

The shaft area running throughout the bearing should have a ground finish and scratches in the shaft that run axially across the bearing must be removed. Minor scratches and grooves that run radially will not stop the bearing from functioning correctly.

This is fairly uncommon but when it does occur, coatings such as tungsten carbide or chrome oxide on the shaft bearing surfaces will prevent any tendency for this problem to occur.

When installing the shaft in the bearings, we must check for bearing to shaft contact. This is done by lightly **blueing the shaft**, placing it in the bearings and then turning the shaft slowly for two revolutions. There should be 75 - 80% contact on both bearings to the shaft. If this contact does not exist, correct for it by first moving the bearing housing and shimming and redoweling the housing. Once any alignment corrections are made, we lightly scrape the area of the bearing that blued with a piece of tool steel until we obtain the correct contact. Then we polish the bearing with scotch brite or equal. This procedure may require reinstalling the shaft several times before an acceptable contact pattern is obtained.

**A general rule of thumb for sleeve bearing clearance is:** Ring oiled - 0.001" + 0.0015" per inch of shaft diameter. Pressure feed bearings - 0.001" - 0.001" per inch of shaft diameter. There should never be less than 0.003" clearance on any shaft. Add 0.001" to 0.002" if the pump shaft will run over 350OF.

The bearings should be replaced if:

- The babbitt bond is broken at the shell
- The babbitt is wiped more than 5%
- There are grooves or cuts in the babbitt over 0.005 deep
- The Babbitt bearing clearance has increased 50% or more over the original clearance.

### OIL RINGS

Oil rings should be made of bronze and be about 1/8" to 1/4" wide. The wider the ring, the more oil that is picked up and carried by the bearing. Heavy rings carry more oil than light rings.

The ring diameter should be 1 3/4 to 2 times the shaft diameter. The thickness of the ring (OD – ID) divided by 2- should be 1/8 inch.

The ID of the installed ring should hang into the oil reservoir from 3/8" maximum to 1/4" minimum.

### THRUST BEARING

thrust bearings must operate square to the shaft and all parts must move freely for the bearing to function correctly.

The thrust disc faces must be parallel and perfectly perpendicular to the bore. The thrust disc faces should be ground or lapped to a 16 RMS finish. The disc should be installed on the shaft from 0.0005" tight to 0.0005" loose. The disc at the maximum face distance should not runout more than 0.0005" TIR with the shaft. The leveling links must all be examined at the wear points. Any worn areas that would not allow the links to freely rock must be replaced or reground. Any contact pivots worn as much as 50% of their diameter must be replaced. If the pivot has any flat sport that retards its free pivoting action, All of the pads should be lapped flat and the overall thickness of the pads should not very by over 0.001". When installed, the pads should have 75% contacts to the disc. The total float in the bearing can be calculated as 0.001 per inch of thrust disc OD plus 0.006.

Example: 8" thrust disc - (8 x 0.001") + 0.006 = 0.014 Total float

**BUSHINGS** -There are numerous types of bushings that are currently used in pumps. The six most common types of bushings

**BRONZE** - A high-leaded tin bronze SAE 660 or equal is used in many different services. It must be lubricated either by the product or by an outside source to properly function. Bronze is easy to install and very durable. It provides an excellent bearing material when matched with 416 SS. pump shafting and is the most popular bearing material in use. All bushing should have a right or left hand spiral of 1/8" wide by 3/32" deep with a 4" pitch to improve lubrication between the shaft and the bushing. Bronze is not recommended for use in very corrosive acid services. The bronze is pressed or shrunk into its holder about 0.001" tight per inch of diameter. Do not knurl any bushings to compensate for lack of tightness when installed.

**CAST IRON** -ASTM A48 class 30 or 40. Cast iron is commonly used in hydrocarbons with good lubricity such as oil or sour crude. It should have the standard spiral groove machined into the bore. Cast iron also makes an excellent bearing material with 416SS pump shafting. Installation is identical to bronze. Cast iron is not recommended for use in water service.

**CARBON**- There are two types of carbon used today. One is the plain graphite carbon such as used in mechanical seal face and the other is carbon that has been impregnated with a metal, such as a Babbitt, nickel or bronze. Both of these types of carbon are self-lubricating. The metal-filled carbon is much stronger and wears better. However, it is more difficult to obtain and costs three to four times as much as plain carbon. Carbon provides a good running bearing material with 416SS pump shafting. Carbon should not be used in abrasive service and carbons should not be lubricated with grease.

The standard spiral grooves should be machines into the carbons. A clean flush will extend the life of carbon bushings. Carbon should be installed into the housing 0.004" to 0.005" tight or 0.0015" per inch of outside diameter. Add 0.0005" per inch of OD per 100oF over 250oF. The ID will close 75% of the interference value after it is pressed into the housing of the carbon. Final clearances of the ID should be equal to or slightly less than the clearances used in bronze bushings. A standard assembly procedure is to soak the carbon in water and press it into the housing at room temperature.

**RUBBER** - The rubber "dog-bone" or cutlass bushing is used extensively in dirty water services. Most of

these bushings are neoprene and are unsuitable for hydrocarbon service. They can sometimes be purchased manufactured from viton, but these are not readily available.
Better service life is obtained with a chrome oxide coating on the 416SS pump shaft in the bushing areas. The clearances in the bushings are molded in by the manufacturer. These clearances typically are much larger than those found in bronze bushings, by as much as 100%.
**RYTON PPS (polyphenylene sulfide)-**This is a polysulfide material that is very resistant to most chemicals. It has physical properties similar to carbon. It is self-lubricating can be used in abrasive service with spiral grooves but runs better with a clean flush.
**TELFON** -This should always be the last choice for a bushing material. It does have good self-lubrication in the virgin state but it will creep and it has a very high thermal coefficient. To counteract the material-flow 15% glass is often installed. This glass will be destroy, a shaft if the equipment is run dry. TFE should be installed 0.005" per inch of OD tight and allowed 35% more running clearance because it expands with heat.

## PUMP PACKING

The most common type of packing comes in a square braided stock. There are a number of different kinds of braided packing. It can be manufactured from jute, asbestos, nylon, Teflon or other synthetics. It can be lubricated with graphite, grease, or other synthetic lubricants such as Teflon. If scored or damaged shaft sleeves and out of round or bent shafts are not going to be repaired , For pump packing need lubrication , don’t run dry packing, some amount of leak is required .

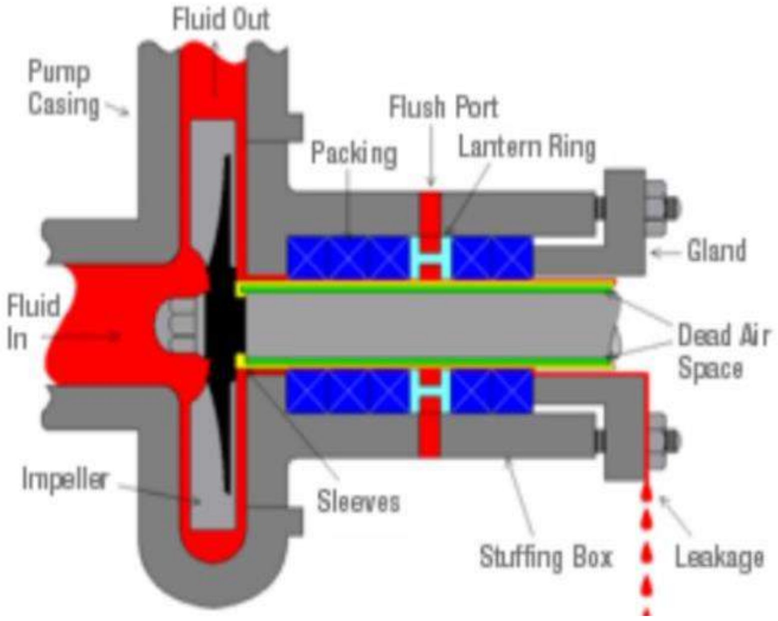
## DAMAGE CAUSED BY PACKING FAILURE

- Loss of prime or suction due to an air leak
- Shaft and sleeve damage
- Water contamination of bearings
- Flooding of pump stations

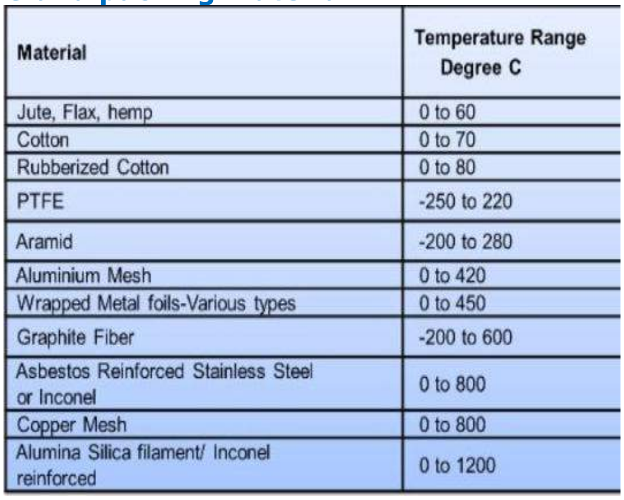
## REMOVING OLD PACKING

It's time to replace the packing when there is no more adjustment left in the packing gland and there is too much leakage from the stuffing box. When this occurs, all of the packing rings must be replaced. Adding an additional ring or just replacing one or two rings will only lead to premature packing failure and damage to the shaft and sleeve. Use the following procedure to remove the old packing:

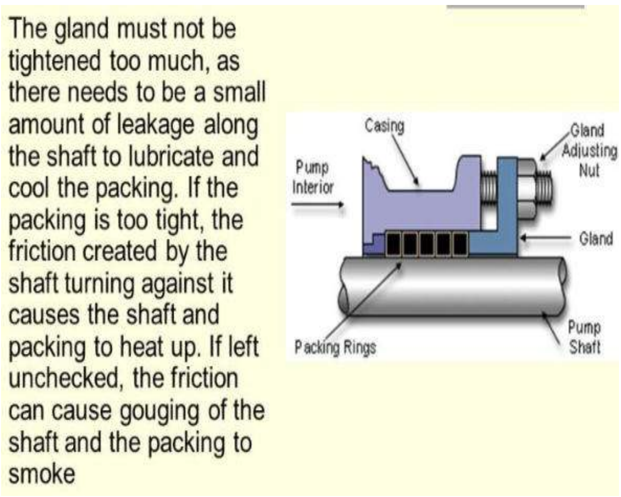
1. Tag the pump in the "OFF" position and lock it out so that it can’t be accidentally restarted.
2. Isolate the pump by closing the suction and discharge valves.
3. Drain the pump by opening the drain cock or removing the drain plug in the bottom of the volute.
4. Remove the packing gland. If it is not split for removal from the shaft, it should be tied off so that it is out of the way.
5. Remove the packing rings with a packing puller (corkscrew on the end of flexible T-handle) taking care not to score the shaft sleeve.
6. Measure the distance to the lantern ring and then remove it with the packing puller. It may take a puller on each side of the lantern ring to pull it out without getting it cocked sideways. If the lantern ring is split, it can be removed from the shaft. If you're not sure the lantern ring was in the right placed to begin with, measure the distance from the face of the stuffing box to the seal water port or refers to the vendor's engineering drawing of the stuffing box for the correct position.
7. Remove the remaining packing rings and clean the stuffing box and shaft.
8. Disconnect, inspect, and clean the seal water line and seal water port.
9. Inspect the shaft or shaft sleeve. If it is scored or grooved, the pump should be dismantled and the shaft dressed or repaired by a machine shop.



## Gland packing material :



| Material | Temperature Range Degree C |
|---|---|
| Jute, Flax, hemp | 0 to 60 |
| Cotton | 0 to 70 |
| Rubberized Cotton | 0 to 80 |
| PTFE | -250 to 220 |
| Aramid | -200 to 280 |
| Aluminium Mesh | 0 to 420 |
| Wrapped Metal foils-Various types | 0 to 450 |
| Graphite Fiber | -200 to 600 |
| Asbestos Reinforced Stainless Steel or Inconel | 0 to 800 |
| Copper Mesh | 0 to 800 |
| Alumina Silica filament/ Inconel reinforced | 0 to 1200 |



The gland must not be tightened too much, as there needs to be a small amount of leakage along the shaft to lubricate and cool the packing. If the packing is too tight, the friction created by the shaft turning against it causes the shaft and packing to heat up. If left unchecked, the friction can cause gouging of the shaft and the packing to smoke

## REPACKING THE PUMP

Before new rings are cut, it is important to determine the size and number of packing rings that are needed for the stuffing box. This information should be available in the vendor's engineering drawings. If these drawings are not available, measurements of the stuffing box and shaft can be used to make the determination.

The correct packing size is determined using the following procedure:

1. Measure the inside diameter of the stuffing box and the outside diameter of the shaft.
2. Subtract the shaft diameter from the stuffing box diameter.
3. Divide the difference by two.

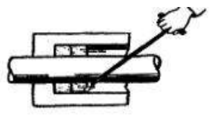
The correct number of rings can be determined using the following procedure:

1. Measure the depth of the stuffing box.
2. Divide the depth of the stuffing box by the size of the packing to get the total number of rings.
3. Subtract one from this total if a lantern ring is used in the stuffing box.

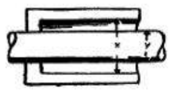
Once the size and number of rings has been determined, the new packing can be cut and installed. Great care should be taken to keep the packing material clean and free from dirt. Packing spools should be stored in plastic bags to prevent contamination. Dirt and grit in the packing rings will lead to serious shaft and sleeve damage. The two most important aspects of cutting packing rings involve cutting them the right length and cutting them so the ends will butt together squarely. Cutting rings the same length with ends that butt together squarely can be accomplished using the following procedure:

1. Cut the packing to the proper length and shape using a very sharp knife or carton cutter. Wrap the packing material around the shaft, an old sleeve, or even a piece of hardwood turned to the proper diameter. Cut all of the rings at once with the packing on the shaft to insure that the ends will butt together squarely.
2. Wrap each ring of packing around the shaft and seat it in the stuffing box completely before adding the next ring. Open the ring by twisting it instead of pulling the ends apart. A light coat of grease on the outside of the ring will make it much easier to push into the stuffing box. Stagger the joints of the rings so that they are 90 degrees apart. Make sure the lantern ring lines up with the seal water port when it is installed.
3. Install the packing gland. Make sure the gland tightened down evenly. It is usually made out of cast material and will break easily if it gets in a bind.

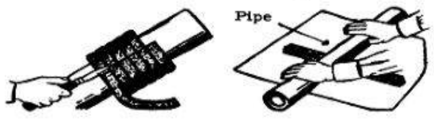
## ADJUSTING THE PACKING GLAND



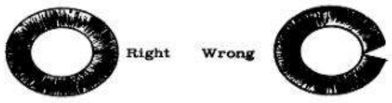
REMOVE OLD PACKING



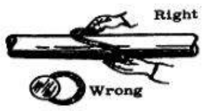
$\frac{X - Y}{2}$ = PACKING SIZE



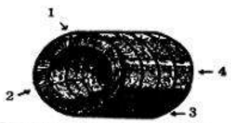
CUT AND FLATTEN PACKING



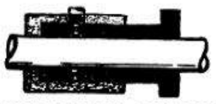
MAKE SURE ENDS ARE SQUARE



INSTALL NEW PACKING



STAGGER PACKING RINGS

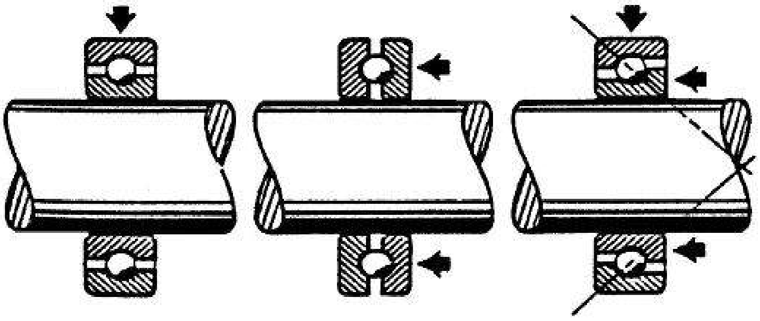


POSITION LANTERN RING PROPERLY

The final adjustment of the packing gland is made while the pump is running. The pump can be restarted once the locks and tags have been removed, the discharge and suction valves are completely opened, and the pump has been primed. More packing jobs have been ruined by improper gland adjustment than any other single reason. Adjust the packing gland using the following procedure:
1. Tighten the gland one half turn a time on each side until it just begins to put pressure on the packing.
2. Start the pump and tighten the gland until the flow of water is reduced just enough to prevent flooding the drain line. Allow the pump to run for at least five minutes while the packing rings seat. Never allow the packing to get hot during this "breaking in" period. If the packing heats up and lubricant is seen oozing from the gland, the packing is already ruined and should be removed and replaced immediately.
3. After five minutes, adjust the packing slowly until the leakage is reduced to the desired level. The appropriate amount of leakage will vary with the size of the pump and type of packing, but a general rule of thumb is 20-60 drips per minute. Tighten the gland and checking the water temperature periodically. When the water turns lukewarm there is not enough flow to cool the packing properly. Loosen the packing gland just enough to cool the water back down to room temperature. The packing gland will probably need to be checked again, as the packing rings get properly seated. This may have to be done several times over the next 24 hours of run time.

## BEARINGS

The bearings in the pump and motor support the rotating equipment and protect it from radial and thrust loads. Some bearings are designed specifically for thrust load applications and will fail if they are subjected to radial loads or thrust loads in the wrong direction. Others are designed to handle radial loads and will fail if thrust loading occurs. Bearings are also made to accept both thrust and radial loads in varying degrees. The design of the bearing races will determine what type of loads a bearing can handle.



Radial loads　Thrust loads　Combined loads

Loading Applications for Ball Bearings

## BEARING IDENTIFICATION

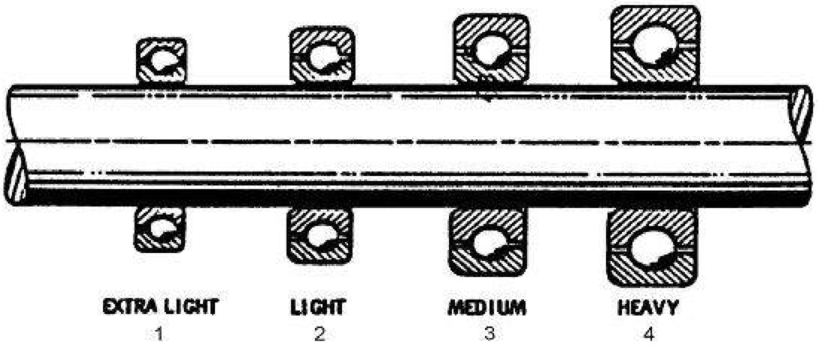
Every bearing should have an identification number on its face that identifies the type and size of the bearing. This identification system is standard for bearings made by the major European manufacturers, i.e. FAG, SKF, NKG. Some bearings that are made by lesser-known manufacturers may not follow the same system. Most bearing suppliers can identify an equivalent for these situations. There are four rules for identifying bearings by number. As with most rules, there are also some exceptions for certain sizes and applications. Bearings that follow this system will be identified by Four numbers, i.e., 7311, 6207, etc.

**Here are the rules for bearing identification:**

**RULE #1** - The first number identifies the type of bearing.
# 6 & 7 SERIES ARE MOST COMMON IN PUMPS
EXCEPTIONS: 22210 - SPHERICAL SELF-ALIGNING & N210 - CYLINDRICAL ROLLER TYPE

**RULE #2** - The second digit from the left identifies the bearing housing size. It represents the amount of load the bearing can carry. The possible ratings are:
9 - Extra-Extra Light
0-1 Extra Light
2 - Light
3 - Medium
4 - Heavy

As an example, a 6310 bearing is a Deep Groove Ball bearing with Medium duty housing. The illustration figure shows some of the different housing sizes for the bearings with the same bore size.



FOUR BEARINGS WITH THE SAME BORE BUT DIFFERENT HOUSINGS SIZES

**RULE #3** - Bores or inside diameters of bearings are measured in millimeters.
EXCEPTIONS: Pillow block bearings and American tapered roller bearings have ID's measured in inches.

EXCEPTION TO THE EXCEPTIONS: Tapered roller bearings on foreign equipment will be measured in millimeters.

**RULE #4** - The last two digits of the bearing number (when multiplied by 5) identify the bore or inside diameter of the bearing in millimeters. As an example, a 6210 bearing has a bore of 50 millimeters (10 X 5 = 50mm)

**TANDEM BEARINGS**: Pumps sometimes have bearings installed in tandem or side-by-side. This is usually an angular contact thrust bearing application. Because they touch each other, it is very important that the housings be machined to special tolerances to insure that the loading is the same on both bearings. NEVER use bearings from different manufacturers in tandem. There will usually be some letters at the end of the bearing model number.

### EFFECTS OF SPEED AND LOAD ON BEARING LIFE

When an engineer decides what type and size of bearing to use in a given application, the decision is based on the calculated speed and load at which the bearing will have to operate. The life of the bearing will be affected by changes in speed and loading on the bearing. Changes in speed will impact bearing life proportionally. If the speed of the bearing doubles, the expected life of the bearing will be reduced by 50%. Changes in load do not have a proportional impact on the bearing life. If the load on a bearing is doubled, the expected life of the bearing will be reduced by 90%.

### BEARING LUBRICATION

Proper bearing lubrication is an important part of getting the designed life out of pump bearings. As strange as it may sound, more bearings have failed from over-lubrication than from lack of lubrication. In fact, some bearings never require lubrication and may fail if they are greased. Shielded and sealed bearings come factory-lubricated and have sufficient lubricant to last the life of the bearing. Shielded bearings have a metal skirt that is attached to the outer race. It covers the rollers but doesn't touch the inner race. Sealed bearings have a rubber skirt that does touch the inner race. Bearings that do require periodic grease lubrication use a surprisingly small amount of grease when compared to the bearing housing size. A properly greased bearing will have a bearing housing that is never more than 25-30% full. The grease is responsible for lubricating and cooling the bearing. Grease that is inside the bearing will get hot as the bearing heats up. When the grease gets hot it becomes more fluid and is thrown out of the bearing and onto the wall of the bearing housing, where it cools. Grease that is outside the bearing is drawn into the race, where it again heats up and is thrown out. This process keeps the bearing lubricated and removes heat from the bearing. If the bearing housing is full of grease there is no way for the hot grease to get out of the bearing. The lubricant inside the bearing overheats and breaks down. The bearing overheats and fails. Lubrication schedules for low-speed (under 2500 rpm) anti-friction bearing applications are based on the operating temperature of the bearing. Always refer to the vendor recommendations for the proper lubricant and lubrication frequency. If vendor data is not available, the following table represents a good rule of thumb for lubrication schedules:

**TEMPERATURE FREQUENCY**

130 degrees F - once a year
150 degrees F - once every 6 months
170 degrees F - once every 3 months
190 degrees F - once every 6 weeks

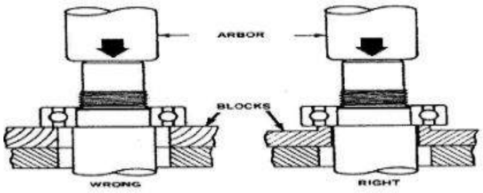
**The following procedure should be used for any grease lubricated anti-friction bearing that is not shielded or sealed:**

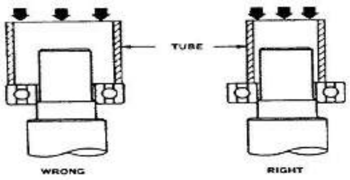
1) Remove the drain plug from the bearing housing. This is usually located on the side opposite the grease fitting.
2) Run the pump for 5-10 minutes prior to adding new grease. Then stop the pump and lock and tag it for maintenance.
3) Waste the first shot of grease from the grease gun to remove contaminated grease from the tip. Add new grease to force the old grease out the drain. Continue until new grease comes out of the drain.
4) Restart the pump and allow it to run for 5-10 minutes while excess grease is expelled from the housing.
5) When no more grease comes out of the drain, stop the pump, re-tag it, and replace the drain plug.
6) Start the pump and allow it to run for 10-15 minutes. Check the bearing temperature. If it is too warm, remove the drain plug and allow the excess grease to be expelled again.

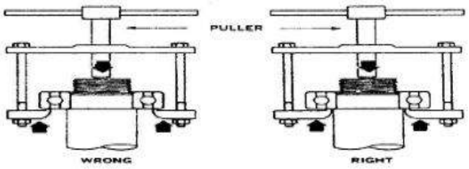
### HANDLING BEARINGS

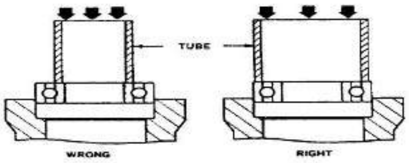
The most important thing to remember when handling bearings is to keep them CLEAN. Dirt in a bearing means damage and reduced bearing life. Always leave a new bearing in its protective wrapping until you are ready to install it. When you are ready to install it, keep the work area CLEAN! Clean hands, clean tools, and a clean work area are critical if contamination is to be kept out of the bearing. The bearing is a precision instrument. It is manufactured to exacting tolerances. It does not take much to damage a bearing. The simple act of spinning a dry or dirty bearing can damage the polished races in the bearing and greatly reduce bearing life. NEVER spin a bearing with compressed air. If you drop a bearing on the floor or a table, the impact will probably cause scratches on the race. A bearing that has been dropped should not be put back into a pump. It is very likely to fail early. NEVER strike a bearing directly with a hammer! Most bearing suppliers will tell you when you strike a bearing you've ruined it. Many a bearing has been ruined before it ever saw any service because of improper handling and mounting techniques.

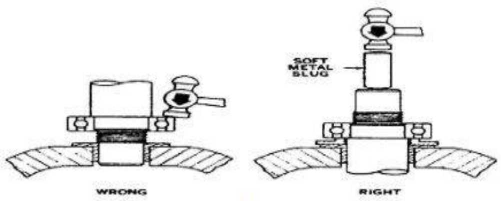
## REMOVING BEARING

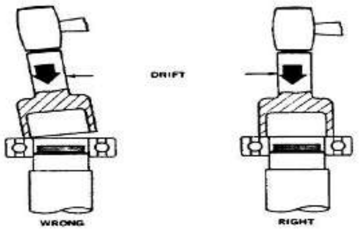












The extreme caution recommended in the removal and re inspection of bearings applies only when it is economically advantageous to consider re-using the bearings. In most cases it is economically wiser to replace the bearings if they must be removed. If bearings are to be re-use it is imperative that you use the right tools and use them correctly. There are several ways to remove a bearing from a shaft. An arbor press is the preferred method, but in the field a bearing puller is more commonly used. Here are some guidelines to follow to properly remove a bearing:

A) Always clean the housing before disassembling it. Never allow loose dirt to get in the housing.
B) Always press or pull the inner ring only. NEVER apply pressure or force to the outer race.
C) NEVER press or pull against shields or cages.
D) Block the press or adjust the puller so that it will pull or push square and straight.
E) When using a puller, make sure not to damage shoulders, keyways, or threads on the shaft.
F) When using a press, provide some means of catching the shaft so it doesn't hit the floor. Make sure the blocks are supporting the inner race.
G) If a vise and drift are used, make sure the vise has brass jaws and never strike the shaft directly with a hammer.

## INSTALLING NEW BEARINGS

Bearings in most pumps are designed to press onto the shaft instead of into the bearing housing. They can be mounted by force (pressed or driven) or they can be heated and mounted without force. Most small bore bearings (2" and smaller) can be pressed or driven on fairly easily. Larger bearings must be heated when installed. Before installing a bearing make sure that the shaft and keyways are cleaned and polished with emery cloth to remove burrs and slivers. The bearing seats should be cleaned any oiled. The bearing shoulder should be cleaned and checked for run out using a dial indicator. If the run out is more than 0.003" the shaft should be reworked to square up the bearing shoulder. Misalignment of the bearing by 0.003" will reduce the bearing life by 90%.

## HEATING THE BEARING

Bearings are heat stabilized to 80-100c This means that even though the metal expands when it gets hot, it will rerun to its original shape if the temperature does not exceed 80-100c When the bearing is heated to 80-100c the inner race will expand enough to allow the bearing to slide on the shaft without the use of force. Bearings can be heated using a small oven to supply dry heat, an oil bath similar to a deep fryer, or a light bulb placed under a steel funnel. The oven supplies a fairly constant temperature that can be monitored, but may not be practical in a field setting. The oil bath heater is messy and may contaminate the bearing if the oil gets dirty. The light and funnel heat the inner race directly, but temperature must be monitored closely. One way to monitor the bearing temperature is with the use of a welder's temperature stick. This is a waxy substance that melts at a specific temperature. Marking the outside of the inner race with a "temp stick" that melts at 200oF allows you to quickly check to see if the bearing is hot enough to mount. Be sure to hold the bearing firmly against the shaft shoulder until it cools. If the heated bearing won't easily slide on the shaft, the shaft can be made smaller by packing it in dry ice to cool and shrink it. Induction heaters that use magnet fields to heat the bearing can also be used. They are fairly expensive, but worth the cost if you have to replace many large bearings.

## PRESSING BEARINGS

Many of the considerations for removing bearings are also true for installing them using force:

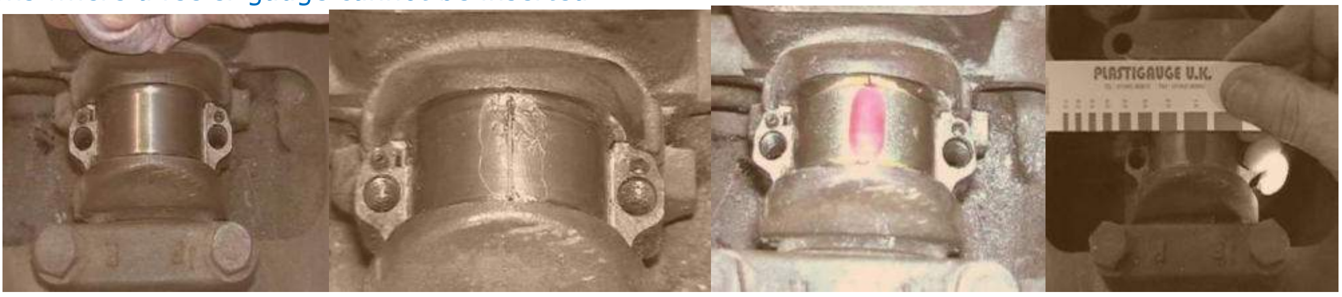
A) Pressure or impact must NEVER be transmitted through the rolling elements.
B) Always make sure the bearing is pressed onto the shaft straight and square.
C) NEVER strike the bearing directly with a hammer.
D) NEVER allow any force to be applied to the shields or cage.
E) If the shaft is held in a vise, make sure to use brass jaws.
F) Make sure the bearing is securely seated against the shaft shoulder.
G) Once the bearing is on the shaft, cover it to protect it until the unit is completely assembled.

**Rules of thumb for pumps:**

- Shut off head H = $(DN / 1840)^2$ , Head ( Dia.of impeller in inch x revolution of impeller (rpm) / 1840)2
- The pumps best efficiency point (B.E.P.) is between 80% and 85% of the shut off head.
- Bearing, grease or lip seals have a design life of less than 2000 hours. In a constantly running pump this would be only 83 days.
- The axial clearance in a bearing is ten times the radial clearance. The life of bearing oil is directly related to its temperature. The rule of thumb used by the Bearing Company is that the service life of oil is estimated to be 30 years at 30 degrees Centigrade (86° F) and its life is cut in half for each 10 degree Centigrade (18 F) temperature increase. This corresponds to :
  - A life of 3 months at 100 C. (212 F.)
  - A life of 6 months at 90 C. (195 F.)
  - A life of 12 months at 80 C. (176 F.)
- Use Centerline pump designs when the pumping temperature exceeds 200 degrees Fahrenheit (100° C). This design will allow the wet end of the pump to expand in two directions instead of from the feet up, destroying the wear rings , Need to do hot alignment , in this case approx. . motor should be 0.2 mm up than pump in vertical
- After the pump and motor have been aligned (below 0.05 mm H & V reading), dowel both the pump and the motor to the base plate. Be sure to dowel only the feet closest to the coupling, allowing the outboard ends to expand with temperature changes.
- Check impeller rotation after installing the pump.
- Use eccentric reducers rather than concentric reducers at the pump suction. Concentric reducers will trap air. Be sure the eccentric reducer is not installed upside down.
- Water in the bearing oil will reduce bearing life 48%. The water enters from packing leakage, wash down hoses, and aspiration caused by the temperature cooling down in the bearing casing after shutdown and moisture laden air entering the bearing case. A 6% water content in the oil will reduce bearing life by as much as 83%
- The mass of the pump concrete foundation must be 5 times the mass of the pump, base plate, and other equipment that is being supported, or vibration will occur.
- Up to 500 horsepower (375 KW), the foundation must be 3 inches (76 mm.) wider than the base plate all around. Above 500 horsepower (375 KW) the foundation should be a minimum of 6 inches (150 mm.) wider.
- The bearing oil level should be at the center of the lowest most ball of a stationary bearing. The preferred choice for bearing lubrication would be an oil mist system with positive face sealing at the bearings, if you could solve the emission problem.

**What is plastic gauge:**

Plastic Gauge provides a simple but precise method for the measurement of clearance between fitted surfaces - mainly plain bearing. It is particularly useful for measuring clearance in split bearings or in situations where a feeler gauge cannot be inserted.



## Clearances for pump:

| No: | Measurement | Tolerance |
|---|---|---|
| 1. | Ball bearing inside diameter (I. D.) to shaft. | 0.0001" to 0.0007" (0.003mm to 0.018mm) interference. |
| 2. | Ball bearing outside diameter (O. D.) to housing. | 0.0001" to 0.001" (0.003mm to 0.03mm) clearance. |
| 3. | Sleeve to shaft. | 0.001" to 0.0015" (0.03mm - 0.04mm) clearance. |
| 4. | Impeller to shaft. | Metal to metal fit to 0.0005" (0.13mm) clearance. |
| **Pumps such as horizontal, axial split pumps and multi-stage vertical pumps that have interference fits.** | | |
| 5. | **Throat bushing** | |
| a) | Throat bushing to case. | 0.002" to 0.003" (0.05mm - 0.08mm) interference. |
| b) | Throat bushing to shaft. | 0.015" to 0.020" (0.40 a 0.51mm) clearance. |
| c) | The throat bushings on some vertical in-line pumps act as clearances. | Intermediate bearings and require closer. |
| 6. | **Impeller** | |
| a) | Impeller ring to hub. | 0.002" to 0.003" (0.05mm -0.08mm interference.) |
| **The impeller ring is normally doweled or spot welded in at least two places** | | |
| b) | Impeller ring to case ring clearance. | 0.010" to 0.012" (0.254mm - 0.3mm) plus 0.001" (0.03mm) per in. (25.4mm) of impeller ring diameter up to a 12" (3,658mm) ring. Add 0.0005 (0.013mm) per inch (25.4mm) of ring diameter over 12" (3,658mm). For temp. > Or = 500 degrees (260 °C) add 0.10" (2.54mm). Also add 0.005 (0.127mm) for galling materials (stainless steel). |
| c) | Renew impeller rings when clearance reaches twice original clearance. | |
| 7. | **Case rings** | |
| a) | Case rings are not to be bored out larger than 3% of original diameter. | |
| b) | Case ring to case. | 0.002" to 0.003" (0.05mm - 0.08mm) interference. |
| **The case ring is normally doweled or spot welded in at least two places.** | | |
| 8. | Oil deflector to shaft. | 0.002" to 0.003" (0.05mm - 0.08mm) clearance. Install "O" ring in the ID if possible. |
| 9. | **Packing gland** | |
| a) | Packing gland to shaft. | 1/32" (0.8mm) clearance. |
| b) | Packing gland to stuffing box bore. | 1/64" (0.016mm) clearance. |
| 10. | **Lantern ring**. | |
| a) | Lantern ring to shaft. | 0.015" to 0.020" (0.40mm - 0.51mm) clearance. |
| b) | Lantern ring to stuffing box. | 0.005" to 0.010" (0.13mm - 0.25mm) clearance. |
| 11. | Coupling to shaft. | Metal to metal to 0.0005 (0.013mm) clearance. |
| 12. | **Seal gland** | |
| a) | Seal gland alignment boss to stuffing box. | 0.002" to 0.004" (0.05mm - 0.10mm) clearance. |
| b) | Seal gland throttle bushing to shaft. | 0.018" to 0.020" (0.5mm to 0.51mm) clearance, unless otherwise specified for hot pumps. |
| 13. | Seal locking collar to shaft. | 0.002" to 0.004" (0.05mm - 0.10mm) clearance |
| 14. | Seal spring compression. | 7/8" (22.2mm) long springs - 3/16"(4.8mm). |
| | | (12.5mm) long springs - 5/32"(4.0mm) |
| | Seal spring compression. | 1/2"(12.7mm) short springs - 1/16" (1.6mm) unless otherwise specified by the manufacturer. |
| 15. | Rotating and stationary seal rings. | Sealing surfaces to be flat within 3 Helium light bands |
| 16. | Heads, case, suction cover, bearing housing to case alignments fits. | 0.004" (0.01mm) maximum clearance. Use dial indicator and feeler gauges to correct fit-up and alignment. |

**(1 thou(0.001”) =0.0254 mm, or 25.4 µm (1 millimeter is about 39.37 thou))**

- **Define the working mechanism of centrifugal pump?**

  Its purpose is to convert energy first into velocity or kinetic energy and then into pressure energy of a fluid that is being pumped. The energy changes occur by virtue of two main parts of the pump, the impeller and the volute or diffuser. The impeller is rotating part that converts driver's energy into the kinetic energy. The volute or diffuser is the stationary part that converts the kinetic energy into pressure energy.
- **How the kinetic energy created by centrifugal force is converted to pressure energy?**

  The energy created by centrifugal force is kinetic energy. The amount of energy given to the liquid is proportional to the velocity at the edge or vane tip of the impeller. The faster the impeller revolves or the bigger the impeller is then the higher will be the velocity of the liquid at the vane tip and the greater the energy imparted to the liquid. This kinetic energy of the liquid coming out of an impeller is harnessed by creating a resistance to the flow. The first resistance is created by the pump volute (casing) that catches the liquid and slows it down. In the discharge nozzle, the liquid further decelerates and its velocity is converted to pressure according to Bernoulli's principle. Therefore, the head (pressure in terms of height of the liquid) developed is approximately equal to the velocity energy at the periphery of the impeller.

- **pump selection factor**

  1) Capacity of pump 2 ) Total head 3 ) Property of liquid to be pumped
  4)Site condition 5 ) Operating condition 6 ) Source of power

- **pump control by following methods**
  1) by throttling / control discharge valve
  2) by – bypass the excess quantity
  3) by using more number of pumps of lower capacity
  4) by using storage tank or reservoir .
  5) by using variable capacity of pump .

**What is pump priming?**

A centrifugal pump priming is done when the passageways of the pump are filled with the liquid to be pumped. The liquid replaces the air, gas, or vapor in the passage ways. This maybe done manually or automatically. Centrifugal pumps are usually filled with the liquid to be pumped before start-up of centrifugal pump. When filled with liquid, the pump is said to be primed. Pumps have been developed to start with air in the casing and then be primed. This procedure is unusual with low-specific-speed pumps but is sometimes done with propeller pumps. In many installations, the pump is at a lower elevation than the supply and remains primed at all times. This is customary for pumps of high specific speed and all such pumps requiring a positive suction head to avoid cavitations. (NPSHa>NPSHr)

**Why the centrifugal pump is called high discharge pump?**

Centrifugal pump is a kinetic device. The centrifugal pump uses the centrifugal force to push out the fluid. So the liquid entering the pump receives kinetic energy from the rotating impeller. The centrifugal action of the impeller accelerates the liquid to a high velocity, transferring mechanical (rotational) energy to the liquid. So it discharges the liquid in high rate. It is given in the following formula:
Centrifugal force F= (M*V2)/R. Where, M-Mass , V-Velocity & R-Radius

- **Why does a reciprocating pump produce a pulsating flow?**

Considering a single-headed, reciprocating pump, the piston moves toward the pump head on the discharge stroke, pressure within the cylinder rises and product is forced through a check valve and down the discharge line. In order to accelerate the fluid to maximum velocity, each piston stroke must overcome the inertia of the columns of fluid in the suction and discharge pipe work. At the end of each stroke, this inertia must again be overcome to bring the fluid columns to rest. This cycle of alternate acceleration and deceleration is the primary cause of fluid pulsations or pressure spikes.

Generally, the application of pulsation dampers is based on one or more of the following criteria:

- to prevent potential pipe hammer / vibration
- to reduce the load on the pump itself
- to minimize or eliminate pulsations for the benefit of downstream instrumentation
- or to minimize or eliminate pulsations as a dictate of process

Flow guard Pulsation Dampers are gas-filled vessels installed on the pipeline. They store up and discharge part of the pump stroke volume by alternately compressing and expanding the gas cushion in synchronization with the motion of the pump. In actuality, these vessels work much like a filter in a power supply as it converts the ripple of a rectified sine wave into DC current.

The gas cushion is normally nitrogen gas and is separated from the process fluid by a flexible membrane (i.e. bladder, diaphragm or bellows). The flexible membrane prevents the nitrogen gas from being absorbed into the process fluid which means very little maintenance (if any) is required during standard operating conditions.

Pulsation damper sizing is based upon the displaced volume per stroke of the pump, pump configuration, gas precharge pressure and desired level of dampening.

- **What is the difference between discharge head & discharge pressure?**

  The main reason for using head instead of pressure to measure a centrifugal pumps energy is that the pressure from a pump will change if the specific gravity (weight) of the liquid changes, but the head will not change. If the discharge of a centrifugal pump is pointed straight up into the air the fluid will pumped to a certain height or head called the shut off head. This maximum head is mainly determined by the outside diameter of the pump's impeller and the speed of the rotating shaft. The head will change as the capacity of the pump is altered. The kinetic energy of a liquid coming out of an impeller is obstructed by creating a resistance in the flow. The first resistance is created by the pump casing which catches the liquid and slows it down. When the liquid slows down the kinetic energy is converted to pressure energy. The term head is used to measure the kinetic energy which a pump creates. Head is a measurement of the height of the liquid column the pump creates from the kinetic energy the pump gives to the liquid.

- **What is vertical in line pump?**

In-line pumps are specifically designed for heating, air conditioning and industrial applications. Suction and discharge nozzles are located 180° apart on the same centerline for mounting directly in a pipe line. This eliminates critical pipe alignment for ease of assembly and minimum pipe strain. The need for costly foundations is eliminated

- **What does a pump develops? Flow or Pressure**.

Pump basically a mechanical device which converts one form of energy to the other.
As per Barnaul's theorem 'Kinetic Energy + Pressure -Energy + Potential Energy = Constant'
Mechanical energy by rotation of impeller is converted to 'Constant' energy. for the flow of fluid.
Depending upon the physical conditions through which the fluid has to flow, the energy in the fluid changes from one type to the other to maintain energy constant? Pump does not develop pressure it just provides a flow, pressure is just an indication of the resistance offered to the flow. Pressure develops flow

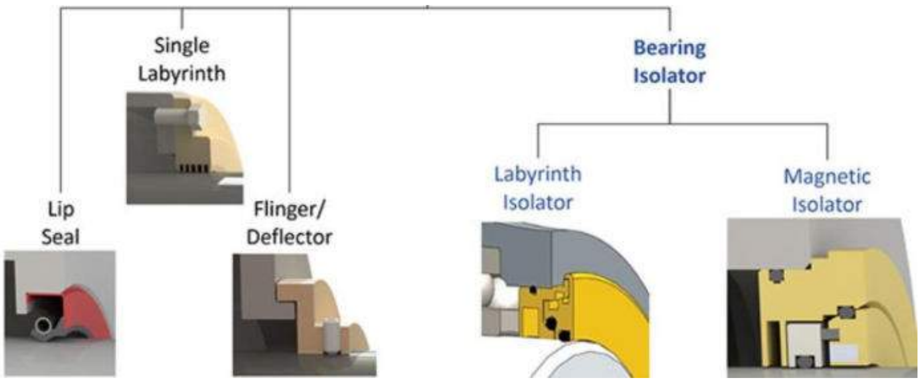
- **Why is vacuum pump smoking?**
  It is normal for the vacuum pump to "smoke" when pumping. Oil-sealed vacuum pumps exhaust a mist of oil when they are pumping. If the pump is smoking and you think it shouldn't be, there must be a leak somewhere. The leak might be in your system or in your pump. Check the gas ballast valve on the pump to be sure it is closed. Try removing the pump from your system and stopper it so it is pumping "dead-headed". If it still smokes, the problem is in your pump and it probably needs repair.

- **What is the purpose of wear rings in centrifugal pumps?** Wear rings can be defined as a device used to seal the pressure leakage of the liquid between the inlet of the impeller and the pump casing. Wear rings are typically found on pumps with closed impellers. A similar device that serves the same function called a wear plate can be found on some pumps with a semi-open impeller. The typical reason for using a wear ring is to decrease the amount of leakage loss around the impeller. The wear rings have three purposes to serve, 1. To decrease the discharge fluid leak to the suction area and maintain the pumps efficiency. 2. It acts as a bearing in a multistage centrifugal pumping system. 3. It is economical to replace the wear rings rather than replacing the expensive impellers in case of any mechanical damage such as, wear and tear due to abrasion or any other reasons.

- **How does axial thrust balance in multistage pump?** A balancing line from discharge end is connected to suction side to balance axial thrust. The axial thrust balance is done by the balancing drum. the inter leaking water at certain pressure will acting on the drum from there the leak will get into the suction line because the pressure of leaking water pressure will more than the suction pressure.

- **What is water hammering / pressure surge of fluid?** When there is a sudden stoppage of flow in a pipe then the pressure wave is generated inside the fluid which travels in opposite direction and it collides with the surface of the pipe wall. This is called water hammering / pressure surge.

- **What is BEARING ISOLATOR?**



The Bearing Isolator is a non-contact seal designed to exclude contaminants and retain lubricant in rotating equipment bearing housings.

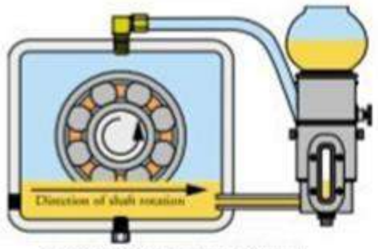
Installation:

1. This Isolator is a one-piece assembly. Do not attempt to separate the rotor from the stator.
2. Lightly lube the housing bore, shaft and stator O-ring with the supplied lubricant.
3. Use a hand arbor press to install the isolator into the housing bore. Typically there is a 0.05mm [0.002”] interference fit. Verify that the expulsion port is located at the bottom-dead-center “down” position.
4. Slide the bearing Isolator and cover onto the shaft as a single unit pushing on the outboard face of the rotor.
5. Verify the rotor turns with the shaft and does not contact the stator. Contact usually means the isolator is not installed square. The isolator is now ready to be put into service.

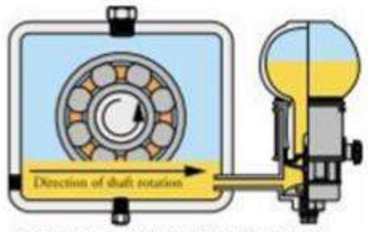
### What is constant oil lubricator in Bearing housing?

A **constant**-**level** oiler can be used to maintain optimum performance / oil level in bearing housing . The **operation** is based on the liquid seal **principle**: as fluid is depleted in the equipment, the liquid seal on the spout inside the **constant**-**level** oiler is broken. When this occurs, air enters into the **oil** reservoir from the air vent.

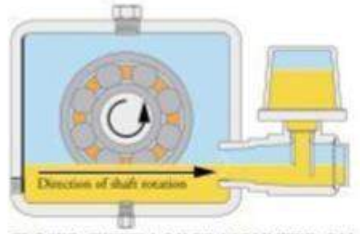
Another concept of the **oil** mist **lubrication** system is dispersion of an **oil** aerosol into the **bearing housing**. Air atomizes the **oil** into particle sizes of one to three microns. Airflow transports these small **oil** particles through a piping system into the pump **housing** which flows through **bearings**.



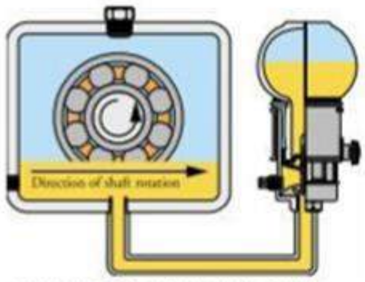
CLOSED SYSTEM OILER WITH
PRESSURE BALANCING LINE



VENTED CONSTANT LEVEL OILER
WITH SIDE CONNECTION



CLOSED SYSTEM OILER MOUNTED ON
CENTER LINE OF DESIRED OIL LEVEL



VENTED CONSTANT LEVEL OILER
WITH BOTTOM CONNECTION

### Difference between ANSI or API pump?

ANSI pumps meet standards set forth by the American National Standards Institute, while API pumps are engineered to standards defined by the American Petroleum Institute.

The API 610 Standard focuses more specifically on refinery and oil & gas applications, whereas the ANSI B73.1 standard applies to a wider range of industries. The ANSI B73.1 Standard allows for interchangeability across 27 centrifugal pump sizes, making this kind of pump ideal for many applications, including food processing, textiles, chemical, pulp & paper, and other types of process plants.

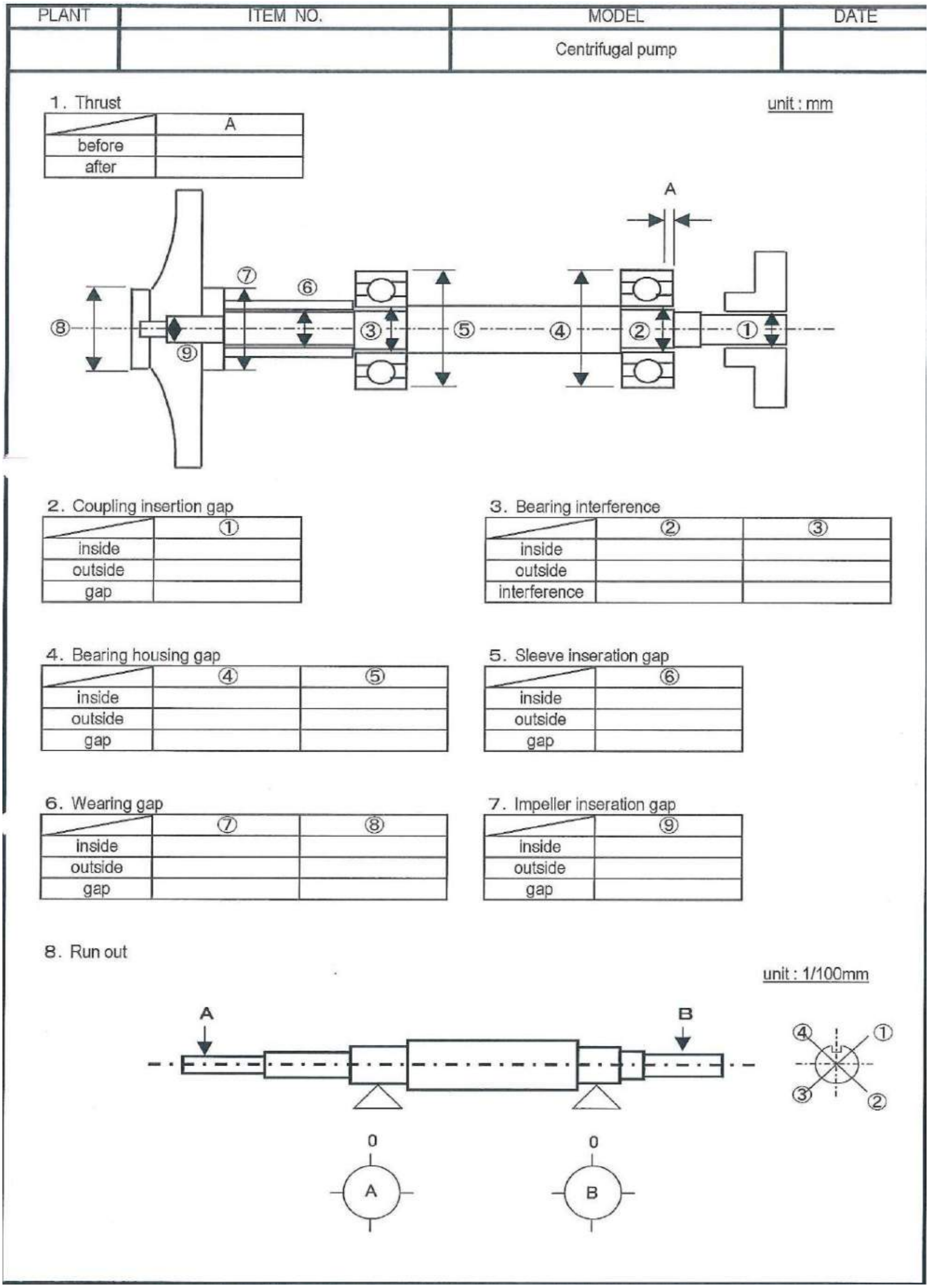
While ANSI pumps can handle a range of different fluids, they do not move thick and highly viscous materials well – unlike API pumps. API pumps are heavier duty and tend to operate more reliably under higher pressures, higher temperatures, and with the capacity to control emissions per EPA requirements.

Typically more expensive than ANSI Pumps, API pumps have some major differences when it comes to the casing design, bearing housings, impellers, mounting, and back cover arrangements.

Casing Design Ratings for Pressure and Temperature – an ANSI pump is rated for 300 psig at 300°F, while an API pump is rated for 600 psig at 600°F.

- Impellers – manufactured without wear rings, ANSI pump impellers are open or semi-open; whereas API pumps feature closed impellers with replaceable casing wear rings.
- Bearing housings – the bearing housings of API pumps tend to be more robust steel design and often accommodate cooling jackets with greater capacity to handle higher temperatures than ANSI pumps.
- Mounting – ANSI pumps are generally foot-mounted, which makes it hard to keep aligned at elevated and varying temperatures as thermal stresses can significantly decrease operational life. API pumps are centerline mounted to counter the effects of thermal expansion and minimize the amount of stress to the casing. *Note: there are some ANSI pumps that are manufactured with centerline mounting.
- Back Cover Arrangements –the back covers in each type of pump are secured differently. In ANSI pumps, the back cover and gasket are held against the pump casing by a cast iron bearing frame adaptor; while in API pumps, the back cover is bolted directly to the casing and uses a compression gasket with metal-to-metal fits

## CENTRIFUGAL PUMP OVERHAUL DIMENSION CHECKING CHART



| PLANT | ITEM NO. | MODEL | DATE |
|---|---|---|---|
| | | Centrifugal pump | |

1. Thrust

unit : mm

| | A |
|---|---|
| before | |
| after | |

2. Coupling insertion gap

| | ① |
|---|---|
| inside | |
| outside | |
| gap | |

3. Bearing interference

| | ② | ③ |
|---|---|---|
| inside | | |
| outside | | |
| interference | | |

4. Bearing housing gap

| | ④ | ⑤ |
|---|---|---|
| inside | | |
| outside | | |
| gap | | |

5. Sleeve inseration gap

| | ⑥ |
|---|---|
| inside | |
| outside | |
| gap | |

6. Wearing gap

| | ⑦ | ⑧ |
|---|---|---|
| inside | | |
| outside | | |
| gap | | |

7. Impeller inseration gap

| | ⑨ |
|---|---|
| inside | |
| outside | |
| gap | |

8. Run out

unit : 1/100mm

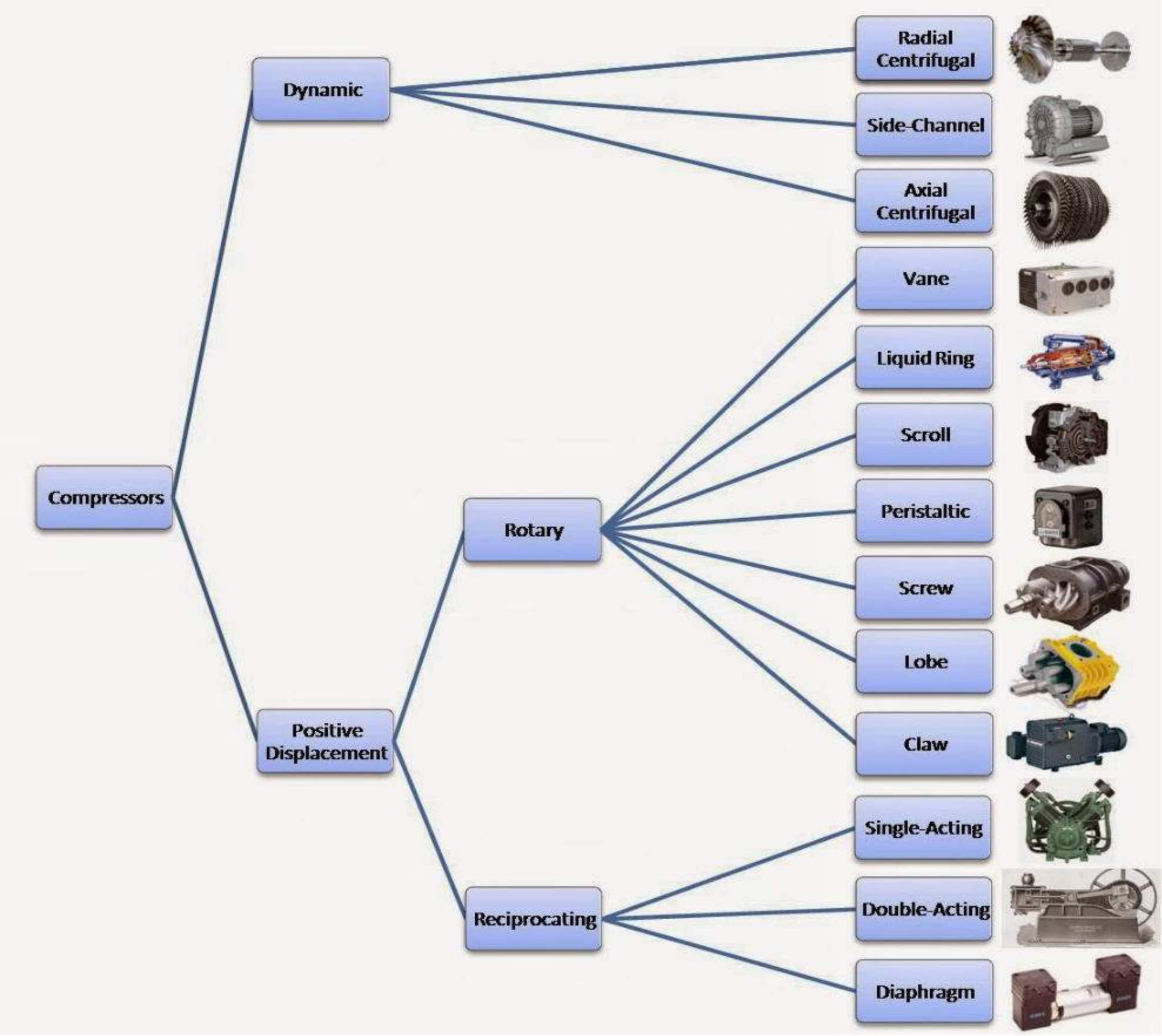
**(1 thou(0.001”) =0.0254 mm, or 25.4 µm (1 millimeter is about 39.37 thou))**

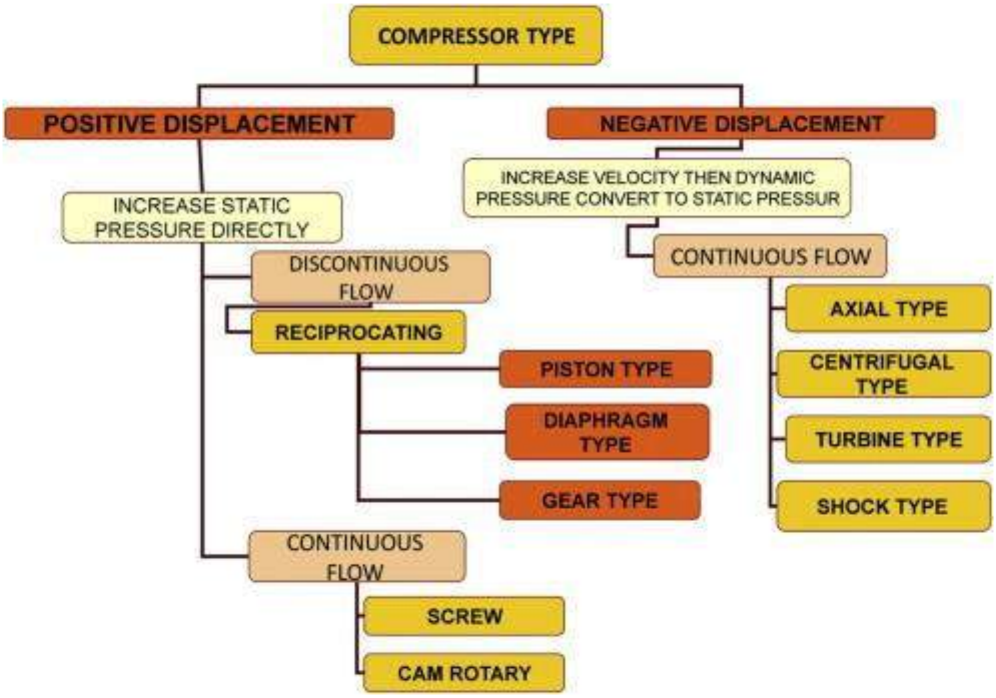
## COMPRESSOR

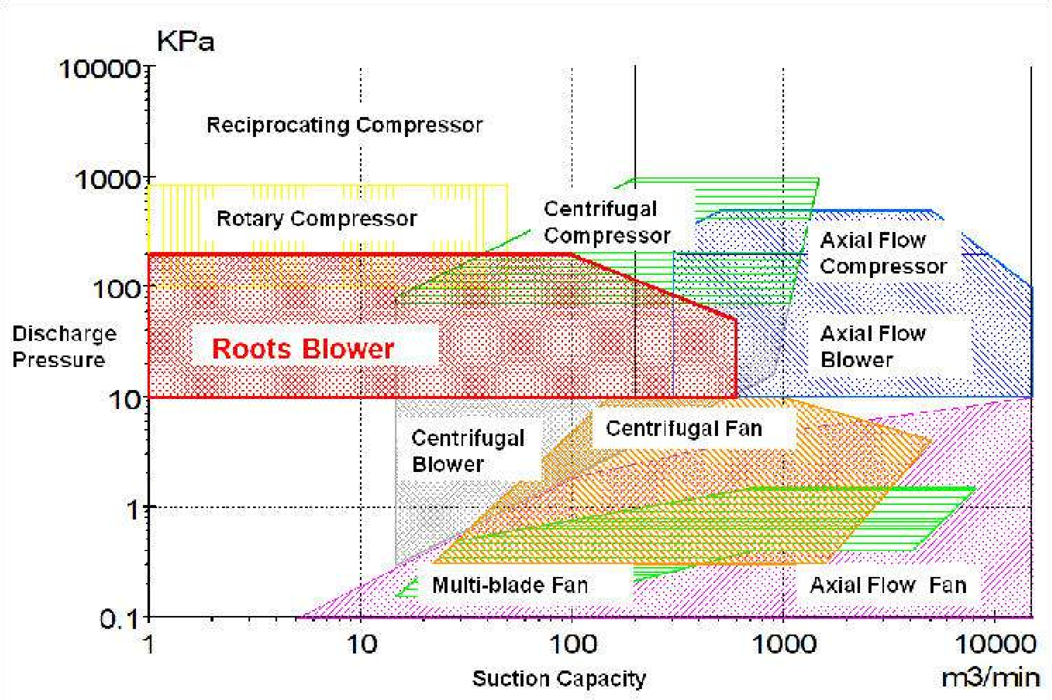
The compressor is a machine, which compresses gases from low pressure to required high pressure. In compressors, mechanical energy is converted into kinetic energy and imparted as thermodynamic energy to the fluid in compression and is exhibited in form of high pressure and temperature of the gases after the compression phenomena.

**Compressors are broadly divided into two main classes**

I) Positive displacement compressor (Reciprocating, rotary compressors)
ii) Dynamic compressor. (Centrifugal Compressors, Axial compressor).


Compressors
Dynamic
Radial Centrifugal
Side-Channel
Axial Centrifugal
Positive Displacement
Rotary
Vane
Liquid Ring
Scroll
Peristaltic
Screw
Lobe
Claw
Reciprocating
Single-Acting
Double-Acting
Diaphragm


COMPRESSOR TYPE
POSITIVE DISPLACEMENT
NEGATIVE DISPLACEMENT
INCREASE STATIC PRESSURE DIRECTLY
INCREASE VELOCITY THEN DYNAMIC PRESSURE CONVERT TO STATIC PRESSUR
DISCONTINUOUS FLOW
RECIPROCATING
PISTON TYPE
DIAPHRAGM TYPE
GEAR TYPE
CONTINUOUS FLOW
SCREW
CAM ROTARY
CONTINUOUS FLOW
AXIAL TYPE
CENTRIFUGAL TYPE
TURBINE TYPE
SHOCK TYPE



In case of **positive displacement** compressor, entrapped gas in some type of enclosure (cylinder or lobes) is pushed out from the enclosure with some mechanical device (Piston or screw) thus reduces the volume of the enclosure and increase the pressure.

In case of **Dynamic compressor**, mechanical action of rotating impeller or blades impart kinetic energy to the gases which then is converted in to potential energy in form of high pressure through diffuser or volute casing.

In both the cases the flow of a compressor is directly related to the speed of the compressor and the intake pressure

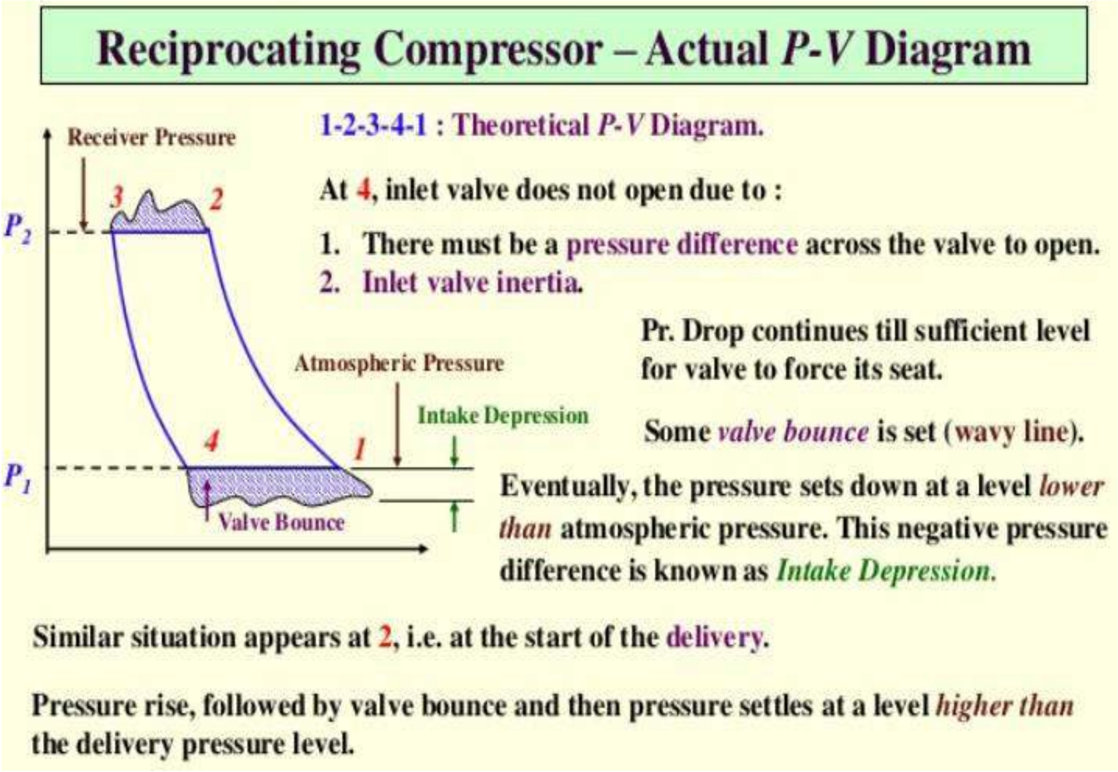
## RECIPROCATING GAS COMPRESSOR:

**Reciprocating compressors are generally made as per API 618**, for general purpose compression services in refinery and petrochemical industries.

In reciprocating gas compressor the fluid (air/gas) is compressed in a cylinder with the help of piston. This compression of fluid can be done in a single cylinder or through consecutive multi stage cylinders in series or parallel, depending upon the process requirement of final discharge pressure and flow.

**Definitions of related terms are given as below:**

**Isothermal** - gas remains at constant temperature throughout the process.
**Adiabatic** - In this process there is no heat transfer to or from the system,
**Polytropic** - This assumes that heat may enter or leave the system.



Reciprocating Compressor – Actual *P-V* Diagram

1-2-3-4-1 : Theoretical *P-V* Diagram.

At 4, inlet valve does not open due to :

1. There must be a pressure difference across the valve to open.
2. Inlet valve inertia.

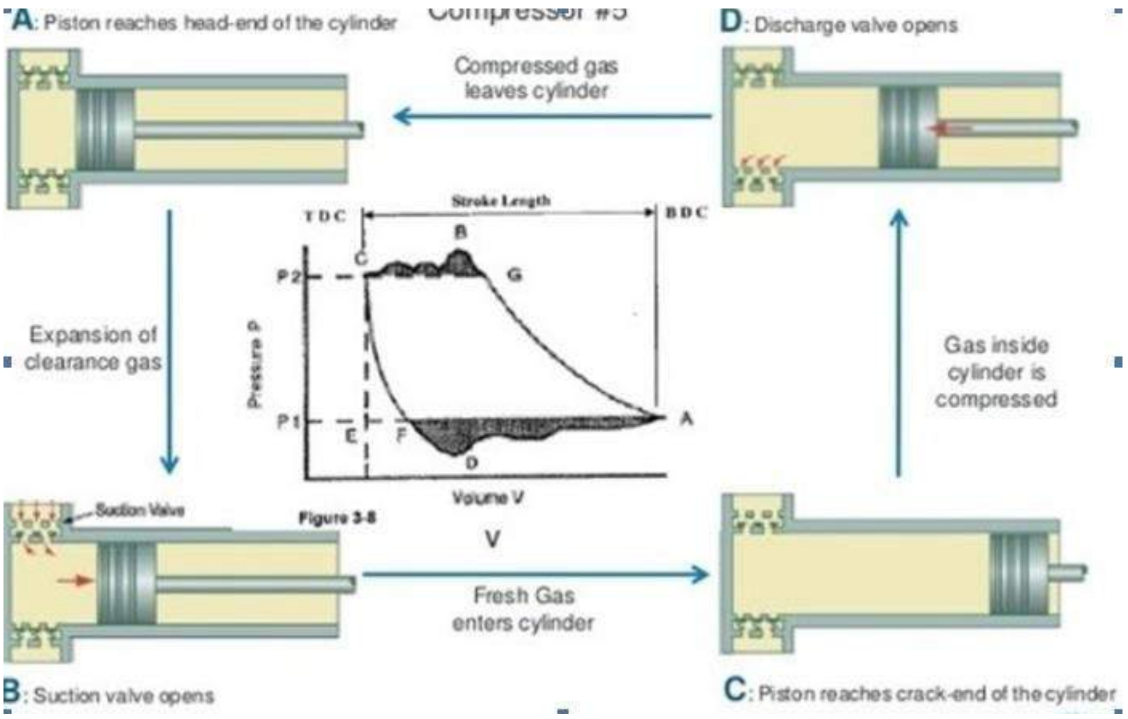
Pr. Drop continues till sufficient level for valve to force its seat.

Some *valve bounce* is set (wavy line).

Eventually, the pressure sets down at a level *lower than* atmospheric pressure. This negative pressure difference is known as *Intake Depression*.

Similar situation appears at 2, i.e. at the start of the delivery.

Pressure rise, followed by valve bounce and then pressure settles at a level *higher than* the delivery pressure level.


A: Piston reaches head-end of the cylinder
Compressor #5
D: Discharge valve opens
Compressed gas leaves cylinder
TDC
Stroke Length
BDC
B
G
C
P2
Pressure P
P1
E
F
D
A
Volume V
Expansion of clearance gas
Gas inside cylinder is compressed
Suction Valve
Figure 3-8
V
Fresh Gas enters cylinder
B: Suction valve opens
C: Piston reaches crack-end of the cylinder

**PISTON DISPLACEMENT:** The piston displacement is the net volume actually displaced by the compressor piston as the piston travels the length of its stroke from BDC to TDC or TDC to BDC and is expressed in cubic feet or meter cubic

**PISTON ROD LOAD**:

In a reciprocating compressor the piston rod is always in cyclic loading condition under compression and tension at discharge and suction strokes of the compressor. Tensile and compressive load cycles goes on repeating. Therefore it become very important to select the material of construction of piston rods which is suitable in this type of cyclic loading.

**LOSSES IN RECIPROCATING COMPRESSORS**:

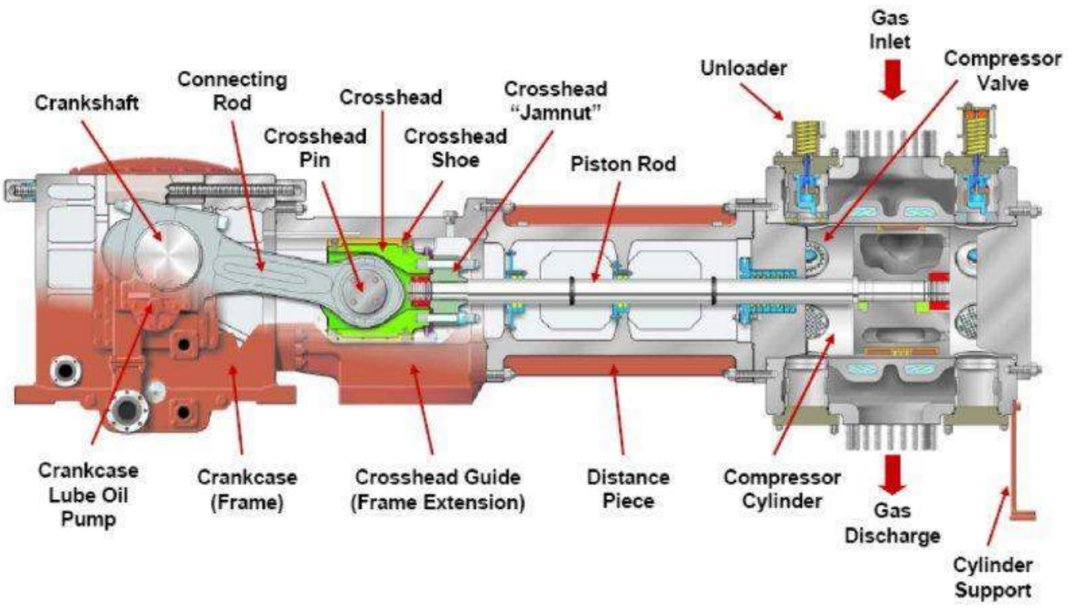
There are many type of losses in reciprocating compressors e.g. suction valve leak losses, discharge valve leak losses, piston ring leak losses, pulsation effects, valve and cylinder gas passage losses and high cushion losses etc.

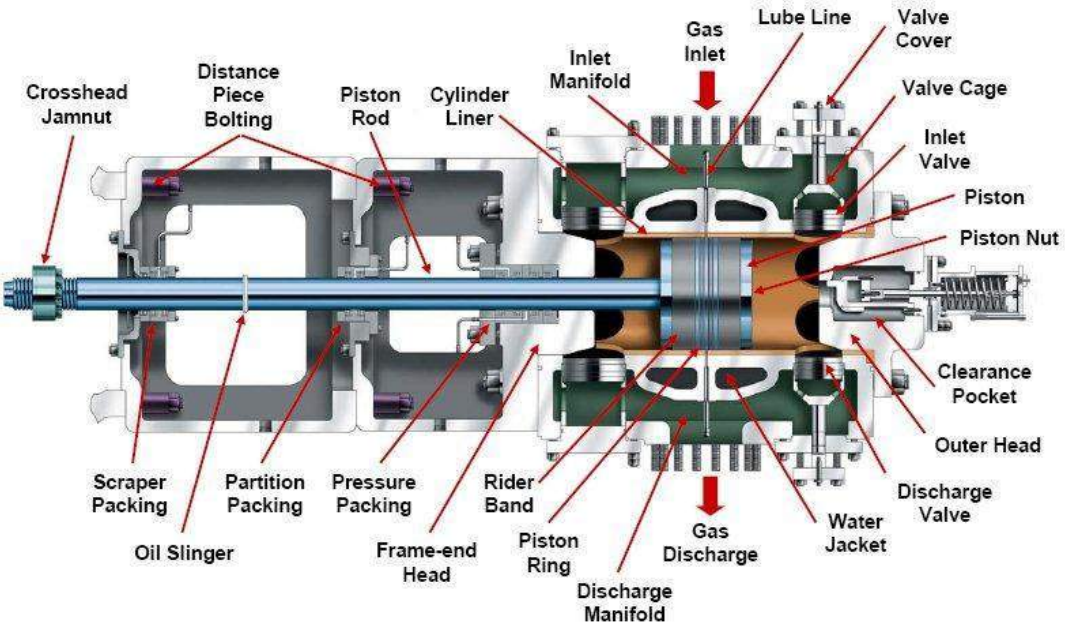
**A general thumb rule is that valve and cylinder gas passage losses should not exceed 5%.**

**Clearance Losses**:

Normally in every cylinder of a reciprocating compressor some clearance is maintained at the head end and crank end of the cylinder, between the heads and respective piston ends (1/4 frame head & 3/4 outer head respect to piston dia.). When the piston reaches at the dead end of its stroke and has discharged all the gases a small amount of gas remains undercharged in the clearance space between piston end and cylinder head. When the piston starts its return stroke this clearance gas at discharge pressure expands up to below the inlet pressure before inlet valves gets opened. This way the clearance gas reduces the volume of the intake gas in the compressor cylinders and thus the efficiency gets reduces.

By increasing the clearance volume of any compressor, the compressor capacity and compression ratio can be reduced. **Generally the recommended clearance volume is 4%~16% of the cylinder volume**.


Crankshaft
Connecting Rod
Crosshead
Crosshead Pin
Crosshead Shoe
Crosshead "Jamnut"
Piston Rod
Unloader
Gas Inlet
Compressor Valve
Crankcase Lube Oil Pump
Crankcase (Frame)
Crosshead Guide (Frame Extension)
Distance Piece
Compressor Cylinder
Gas Discharge
Cylinder Support


Crosshead Jamnut
Distance Piece Bolting
Piston Rod
Cylinder Liner
Inlet Manifold
Gas Inlet
Lube Line
Valve Cover
Valve Cage
Inlet Valve
Piston
Piston Nut
Clearance Pocket
Outer Head
Discharge Valve
Water Jacket
Gas Discharge
Discharge Manifold
Piston Ring
Rider Band
Frame-end Head
Pressure Packing
Partition Packing
Scraper Packing
Oil Slinger

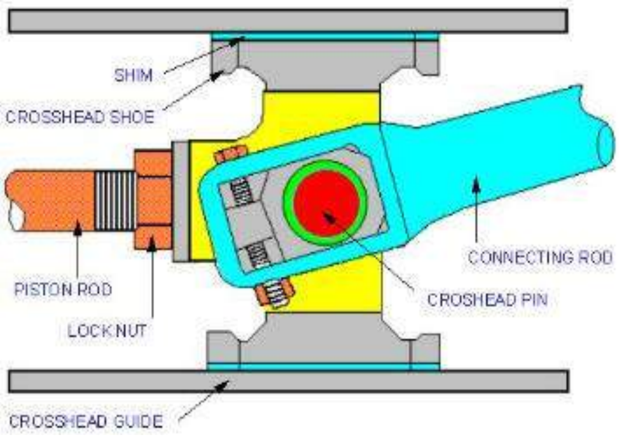
Cylinder assembly of reciprocating Compressor

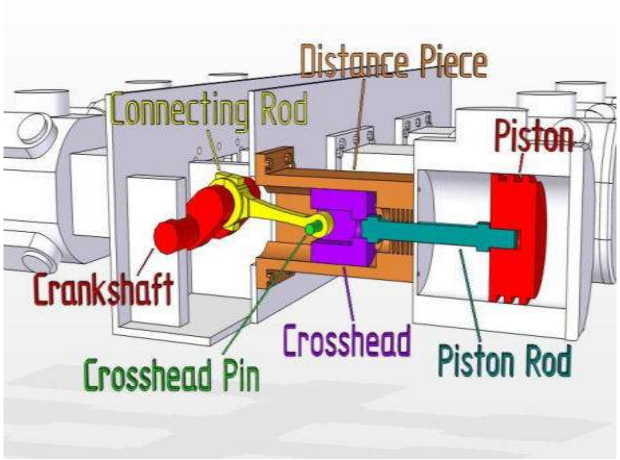
**Capacity Control of a Compressor:**

In many applications it is required to vary the capacity of a compressor to meet changing process needs. There are several ways to accomplish this capacity control in reciprocating compressors e.g.

1) By variable speed of driver,
2) By manual un-loader valves,
3) By pneumatic or hydraulic finger un-loader valves,
4) By fixed volume & variable volume clearance pocket and
5) By opening the by-pass valve at the discharge of the initial stages.

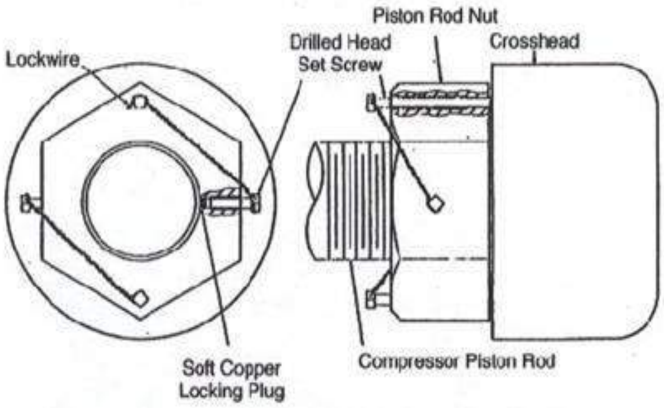
## General Crosshead and Piston rod arrangement with Oil wiper rings


SHIM
CROSSHEAD SHOE
PISTON ROD
LOCK NUT
CONNECTING ROD
CROSHEAD PIN
CROSSHEAD GUIDE


Distance Piece
Connecting Rod
Piston
Crankshaft
Crosshead
Piston Rod
Crosshead Pin

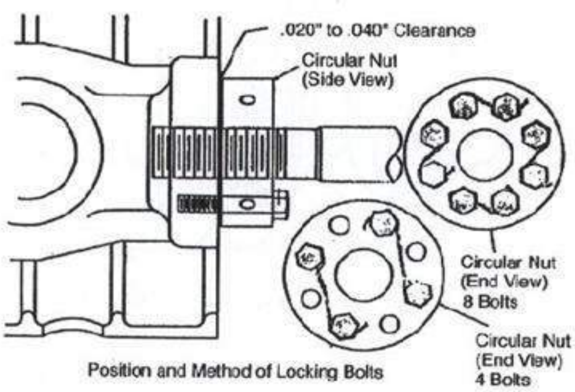
## Conventional Piston rod locking arrangement with Crosshead

In this arrangement a hexagonal nut of same thread of piston rod is tightened against the cross head face and then locking pin or dowel is inserted along and perpendicular to the piston rod axis to prevent rod rotation


Piston Rod Nut
Drilled Head Set Screw
Crosshead
Lockwire
Soft Copper Locking Plug
Compressor Piston Rod

## Multi-Bolt Type Modified Piston rod locking arrangement

In this arrangement circular nut/bush with same thread of piston rod is used instead of conventional hexagonal nut and multiple torque bolts as per torque required is used to fasten the round nut/bush with the cross head face. These bolts actually lock the piston rod. It is very easy to assemble and dismantle the piston rod as torque bolts are very small as compare to conventional hexagonal cross head nut.


.020" to .040" Clearance
Circular Nut (Side View)
Circular Nut (End View) 8 Bolts
Circular Nut (End View) 4 Bolts
Position and Method of Locking Bolts

## Sealing of Reciprocating Compressor:

Compressor sealing consists of a series of packing/sealing elements which is installed into piston rod gland packing housing and each packing/sealing element restrict the flow of gas one after another and thus prevent gas leakages into atmosphere. No compressor sealing is 100% seal proof. There will be some gas leakages which is collected through vent rings and again may be recycled to suction depending upon the back pressure. The sealing/packing elements are held in separate cups within a packing case. The each sealing rings seals in two directions i.e. against the piston rod and against the packing cups perpendicular to the piston rod axis. Seal rings are free to move laterally along with the rod and free to float in the packing cups.

Conventional piston rod packing consists of following things

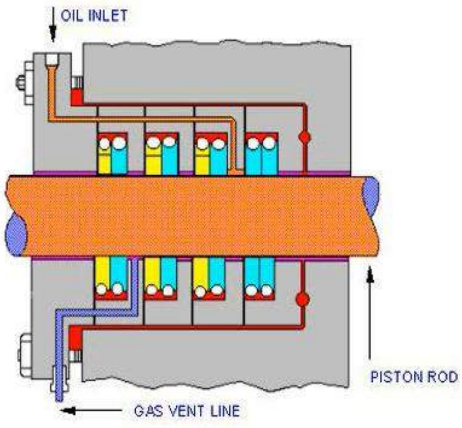
- Pressure Breaker which functions as a flow restricted or to break the initial pressure. Another important function of the pressure breaker is to restrict rapid expansion of gas from the packing case into the cylinder during the suction stroke as in the suction stroke gas contained in the packing case (leakages through packing elements during compression stroke and accumulated into packing case) tend to flow back into cylinder where the pressure is dropping rapidly to suction pressure. If this back flow of gas is not restricted an exploding action of the sealing/packing elements may occur which may cause premature packing failure. Pressure breaker is not generally required when pressure is below 300 psi.
- Number of Sealing/packing elements (Actual number of sealing rings depends upon the suction and discharge pressure of the compressor)which actually seals the leakages
- Vent Ring which stops the leakages of gas from the last sealing rings into the atmosphere.

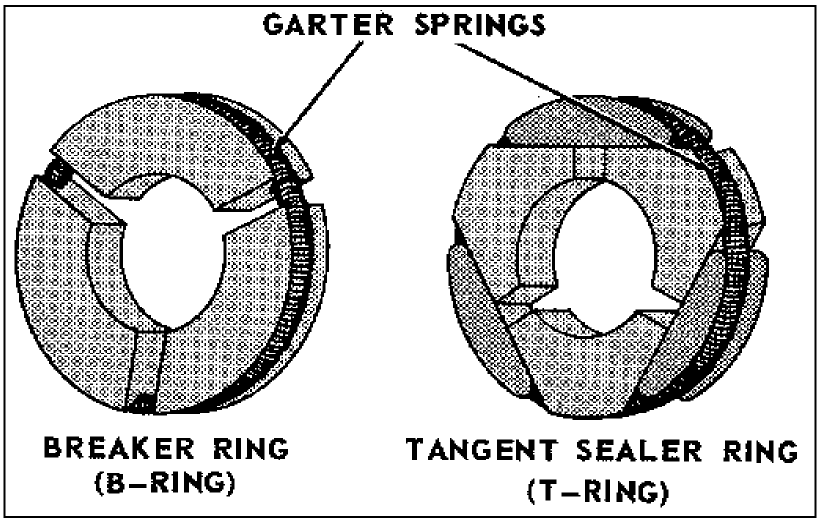
Compressor sealing assembly may be lubricated; water cooled or may not depend upon the application/services. Pressure drop is highest across sealing rings nearest pressure side when the sealing rings are new and as sealing rings/packing rings wears, the downstream rings are experienced more pressure drop as the path of leakages increased with wear. A reverse drop exists across some rings during suction stroke i.e. gas will flow back into the cylinder from the packing case.

**Conventional piston rod packing consists of one metallic radial cut rings and one metallic tangential cut rings** i.e. one set of radial cut and tangential cut rings installed in one packing cups and there may be several packing cups. Vent ring consists of two tangential cut rings.

In case of Sandwich packing each packing set consists of one radial cut metallic rings, one tangential cut non metallic rings and one metallic radial cut back up or anti extrusion ring.

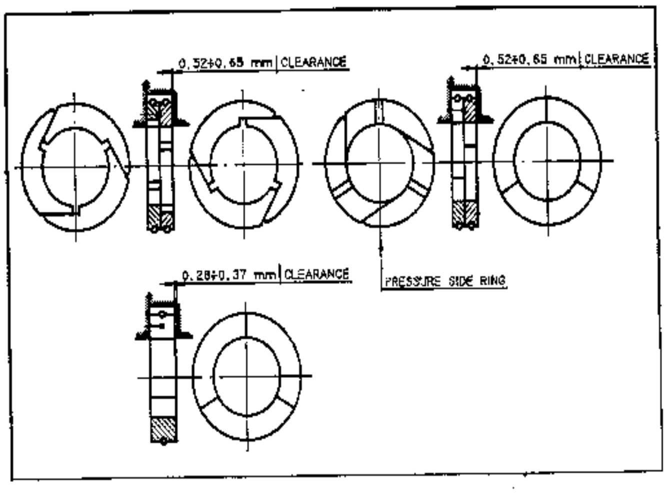
In some cases both the radial cut and tangential cut may be non metallic rings but the anti extrusion ring must be metallic.

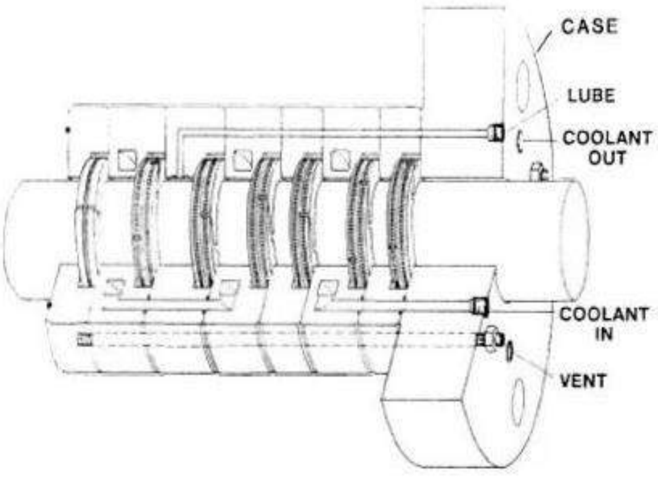




**The material of metallic rings may be bronze, cast iron Babbitt etc and the non metallic rings may be of carbon graphite, PTFE, PEEEK or other plastic materials.**

## General Piston Rod Packing Assembly


0.52±0.65 mm | CLEARANCE
0.52±0.65 mm | CLEARANCE
0.28±0.37 mm | CLEARANCE
PRESSURE SIDE RING

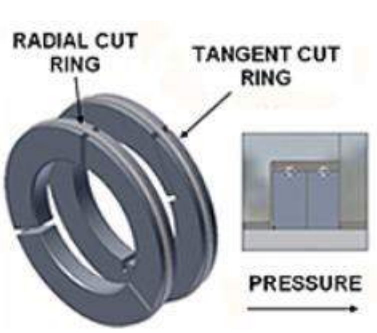

CASE
LUBE
COOLANT OUT
COOLANT IN
VENT

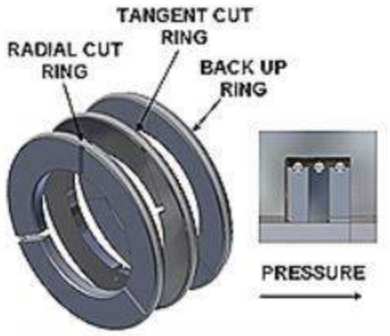
## Construction of Tangential Rings and Fluid Pressure on Packing/Sealing Elements

### Wiper Ring or Oil Scrapper Ring or Diaphragm Packing:

To scrap out the oil from the moving piston rod, oil scrapper ring or Oil wiper rings are installed in the Diaphragm assembly between the cross head guide distance piece and the Cylinder block and the scrapped oil is drained back to crank case frame. One set of Seal ring (Tangential ring set) is also installed with oil scrapper ring in the diaphragm for the breathing action of the crosshead.

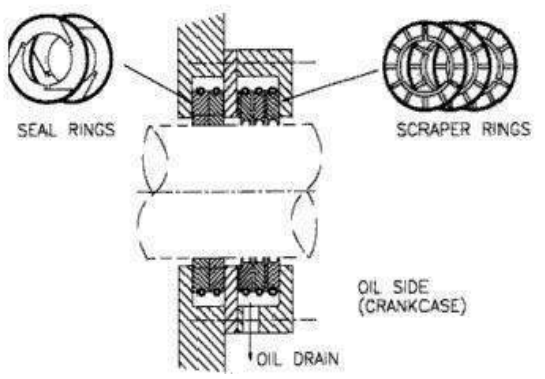
These wiper rings and seal rings are generally made of bronze material and are locked by Garlok springs. These rings should be free to slide with each other but should not have high axial clearance

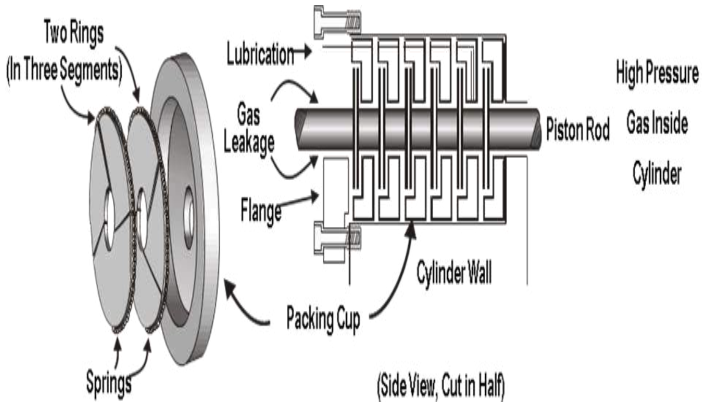

RADIAL CUT RING
TANGENT CUT RING
PRESSURE


TANGENT CUT RING
RADIAL CUT RING
BACK UP RING
PRESSURE

**Wiper Ring set without tangential seal rings** **Wiper Ring set with Tangential seal rings**

These are the basic and most commonly used wiper ring combinations. The only **function of these rings is to wipe the rod and drain the fluid away.** The three ring configuration is doweled to prevent alignment of cuts with respect to each other.


SEAL RINGS
SCRAPER RINGS
OIL SIDE (CRANKCASE)
OIL DRAIN


Two Rings (In Three Segments)
Lubrication
Gas Leakage
Flange
High Pressure Gas Inside Cylinder
Piston Rod
Cylinder Wall
Packing Cup
Springs
(Side View, Cut in Half)

## Maintenance Activity of Reciprocating Compressor:

**Generally in reciprocating compressor the frequency of replacement of piston rings, piston rod packing, valve assembly, piston, piston rod, cylinder liner is high. In nominally well lubricated machines, the main bearing, big end bearings, cross head pin bearing, cross head pin, cross head shoe, connecting rod, crank shaft are very rare and generally replaced once in a while due to some major problem in the system**.

Important parameters, which shall be noted during maintenance of compressor and taken care, are as below:

- ✓ ID of cylinder liner
- ✓ Grooves of piston rings and rider rings on piston
- ✓ Crank End & outer end (head end )and side clearances of piston rings / rider rings
- ✓ Perpendicularity of piston ring groove walls
- ✓ OD of piston rod at various locations.
- ✓ Depth of packing cups
- ✓ Floating of packing rings
- ✓ Perpendicularity of packing cups to rod axis

- ✓ Cross head pin bush clearance
- ✓ Cross head shoe clearance
- ✓ Deflection of piston rod
- ✓ Seat of valve housing in valve port
- ✓ Lift of valve plates
- ✓ Surface of valve seat
- ✓ Diaphragm packing etc.

The above measurements shall be taken on the protocol format and shall be compared with the original dimensions. Dimensions of parts shall be within permissible limits of variation otherwise replacement of the affected part shall be planned. weared out parts if used may fail without giving significant life and may deteriorated other mating parts also. Such failure may arise without any explanations.

The end gap and side clearances of piston rings/rider rings should be maintained according to OEM or manufactures recommendations. **Too much side gap will break the piston rings due to high relative motion in the piston ring grooves and higher end gap will blow off the piston rings. Excessive tight clearance will seize the piston rings in the piston ring grooves and no compression will be achieved in that cylinder. These clearances are kept considering the difference of coefficient of thermal expansion of the rings at operating temperature with respect to piston**. These values depend upon the material of construction of piston rings and piston.

The following malfunctions can occur to a compressor cylinder regardless of the gas pumped and whether or not it is double acting or single acting, large or small diameter, multistage or single stage.

-Exceeding assigned rod load

-Accelerated wear and scuffing

a)Piston to liner

b)Piston rings

c) Piston Rod Packing

-Valve breakage

-Knocks, noises and vibration

**Exceeding Assigned Rod Load**-It is essential that operators and mechanics should understand rod load. Most major casualties such as broken piston rods, damaged crossheads, cross head pin, broken cylinder to distance piece or distance piece to crankcase or frame failure are generally caused by exceeding the maximum rod load. This failure does not occur instantly exceeding the rod load but, after prolong operation in over rod load condition. The frightening aspect of that the failure can happen within just few revolutions after the infraction or after a period which slowly deteriorate the machine condition and at last failure. By explanation when the piston moves towards head end the discharge pressure force (Pd)on the piston ends tends to compress or buckle the piston rod. At the same time in the gas is entering into the cylinder behind the piston at suction pressure (Ps) and putting suction pressure force at the back of piston. **The two force are opposite in direction but since discharge pressure is higher than suction pressure the net force tends to compress the rod which is called "Rod Load Compression".** So it is basic that if the suction pressure decreased or discharge pressure increased the net compression load on the rod increases. So it is very necessary that there should not be too much pressure deviation in suction and discharge pressure. **Again when the piston moves toward crank end and compressed gas the net force of the suction and discharge pressure results in tension load on the rod which is called "Rod Load Tension".** Although the tension and compressive forces are absorbed by the rod , other parts such as head bolts, piston, connecting rod and bolts, crosshead, pin bushing, frame are likewise stressed. Loading and unloading cylinders of multi stage compressor changes inter stage pressure and so the compressor should be loaded and unloaded very carefully and sequentially and also start up of compressor to avoid any abrupt change in inter stage pressure which can exceed the rod load.

**Knock, noise and Vibration:** Knock noises and vibration are good indications of trouble. The maintenance people should have enough knowledge about the knock and noises and it should not be misinterpreted which can create panic. **A common type of knock is caused due to hitting of piston at the end(cross head side & outer head side) caused by improper clearance. Another type of knock sound may come due to loosening of piston nut. This is the nut that secures the piston with the piston rod .If it becomes loose by 0.003 inch it will knock very loudly. Other type of knocking sounds are due to lose valve assemblies, liquid carry over, loose piston rod packing assembly.**

**Crank Shaft Deflection**:_The crank shaft web deflection can be measured with connecting rod assembly and without connecting rod assembly but, it is advisable to measure/check without connecting rod as this will give the exact true value. With connecting rod the deflection can be taken from the given formula. When measuring without connecting rod the web gauge can be installed in position A and in case of with connecting rod the web gauge should be positioned at point B with special deflection gauge attachment and with the following calculation. If the deflection gauge is positioned at point B which is out on the counterweights, the deflection recorded there would be twice the actual deflection measured at point A.

Measuring point A: Normal (Measure without connecting rod)

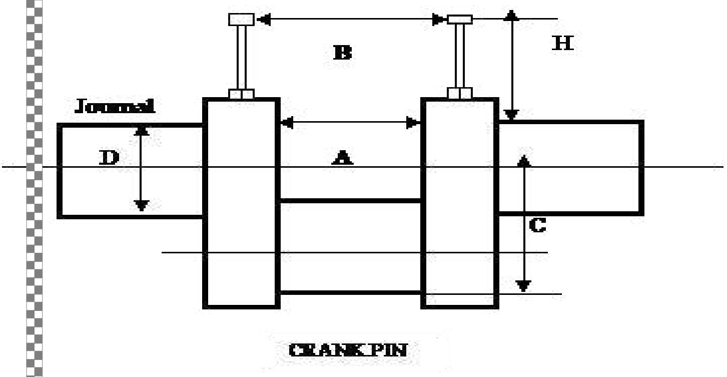
Measuring point B: Extension (Measure with connecting rod)

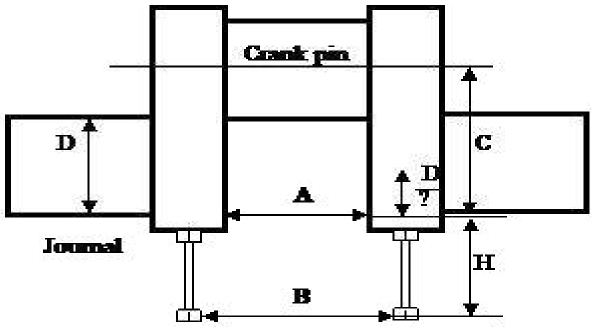
When measure deflection at B point, calculate to A value.

Deflection A = B X C/(H+C)

B= Actual Reading Value at B Point

C= Stroke/2 + D/2





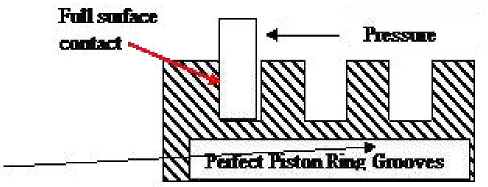
Suppose the crank pin is at down position and this is designated as Zero or starting position. Let us assume that the main bearing journal to the right is low due to bad or worn-out main bearing. The crank web would then be spread apart. The web gauge is set to zero at this position and when the crank is rotated to the up 180 degree position the web move inwards which registered a minus (-) reading on the dial. If the starting point sets to crank pin up position then the reading will be reversed i.e. when the dial gauge is set to zero position at crankpin upwards and then after rotation 180 degree rotation the webs would spread and the dial would register a plus(+)movement. The magnitude of deflection in both cases for the same cause (bad bearing or lower pedestal) but, the sign (+), (-) of the dial gauge would be reversed.

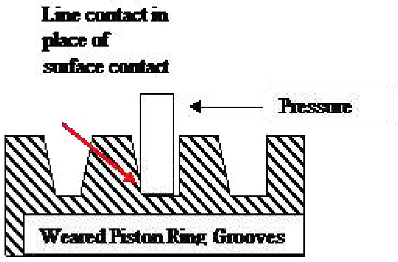
Generally deflection at 0 degree and 180 degree i.e. up and down position of crankpin is taken to judge whether the clearances of main bearing ok or not, or whether the crank shaft is sagged or bowed due to bad bearing or bearing pedestal lowered .The 90 degree and 270 degree positions are normally used to determine whether the main bearings are out of alignment in a horizontal plane. If the bearing saddles are out of alignment in a horizontal plane, the signs at 90 degree and 270 degree would be reversed but if the 180 degree position has excessive deflection caused by journal being low , the reading may carries up to 90 degree and 270 degree. So it requires experience to correct the deflection. Sometimes the reading will be high at 0 degree and 180 degree but the bearing clearances may be found ok and this is due to lowering of frame pedestal, so in this case the level of frame should be corrected. The severity of deflection depends upon the length of stroke and RPM of the crank shaft. As the same deflection may be tolerable in low RPM and the same deflection may be unacceptable at high RPM as in case of high RPM the frequency of web inwards and outwards will be more than low RPM.

## EFFECT OF WEARING OF MOVING PARTS

### Piston Ring Grooves / Piston Rings:

The grooves wall surface of the piston rings in the piston should be perpendicular to the piston axis and should be within tolerance limits of dimension. Generally after prolong use of piston the piston rings, grooves size gets changed and sometimes may become taper as shown below. This variation in groove size may increase the gas leakages along the piston rings. Due to damaged or tapered piston ring grooves the piston rings does not get full surface contact with the piston groove wall. In such cases, due to line or point contacts, piston ring malfunctions in the compression stroke and may failed early.



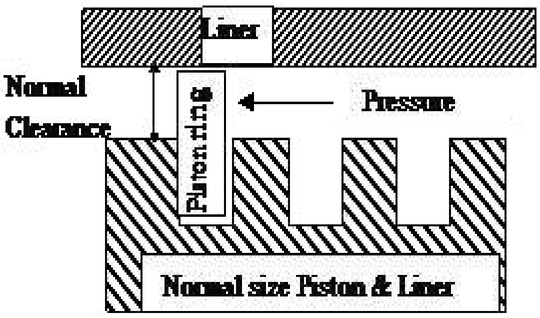

Line contact in place of surface contact
Pressure
Weared Piston Ring Grooves

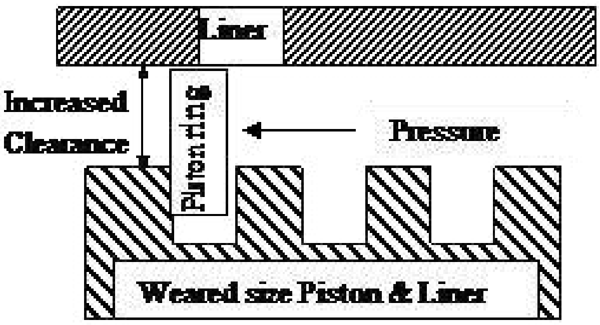
Effect of Wearing of Piston Ring Grooves.

### Piston / Cylinder Liner:

If the piston OD get reduced due to worn out or Cylinder Liner ID gets enlarged, then piston to liner clearance will be more, the projection of the piston rings will become more than the desired/designed values. In such case, Piston rings will be subjected to higher thrust load and similarly piston rings groove wall will also be experiencing increased thrust load. Weak material in this case will break away, it may be piston ring or piston rings groove wall.

With increased piston-liner clearance, piston will also experience jumping during the motion. This jumping is very deteriorating for piston rod, Cross head nut etc.





## MAINTENANCE OF PISTON ROD PACKINGS:

Piston rod packing is very important element for the reciprocating compressors and plays crucial part in efficiency of the compressor. There are many types of packings' available in market for different services however common features are lubricated or non lubricated packings'. In the packing assembly lot of heat is generated and packing elements may loss their properties at high temperature if heat is not removed from the assembly. Generally cooling water connection is done in a way to indicate flow of water through packing assembly. It may be with flow indicator or return line is kept open to atmosphere.

During replacement of piston rod packing the installation of packing elements in the piston rod packing cups plays an important role. The packing elements should be as per sequence recommended by manufacturer, i.e. **radial cut rings should face towards pressure side and tangential cut or seal ring should face cross head side. In case of sandwich packing the radial cut metallic rings faces pressure side, tangential cut non metallic rings(Sandwich) works as sealing rings which actually seals the leakages and anti extrusion ring or back up metallic rings after seal ring towards cross head side**. The back-up ring is generally larger in ID as compared to seal ring. The backup rings takes the heat generated by the radial cut ring and tangential cut ring and dissipated the heat.

The floating or axial clearance of packing ring elements in the packing cups should be as per OEM or manufactures specification and this also depends upon the material and type of packing i.e the depth of packing cups grooves should be more than the thickness of the packing rings. Generally the floating should be 0.15 ~0.20 mm. It actually depends upon the thermal expansion of the packing elements during actual operation .

The packing cups face should be properly lapped before assembly to prevent any leakages and should be perpendicular to the axis of the piston rod. all elastomers should be of proper dimension and material and of required shore hardness. If the packing is lubricated and water cooled then the passages for lubrication and cooling water should be clear and in sequence.

The performance of piston rod packing also depends upon the deflection of the piston rod and deflection also depends upon the piston OD , cross head shoe liner clearance and ID of the cylinder liner. The axis of the piston rod, seal housing, cylinder liner and cross head should be in perfect alignment.

## VALVES:

Valves are the elements which allow the gas to flow inside the compressor and from the compressor to the high pressure system. These are called inlet or suction valve and outlet or discharge valves respectively. For reciprocating compressors, valves are the most venerable part for the maintenance. Normally life could not be predicted for the valve assemblies however good quality valves gives quite good life.

*Poppet valve*

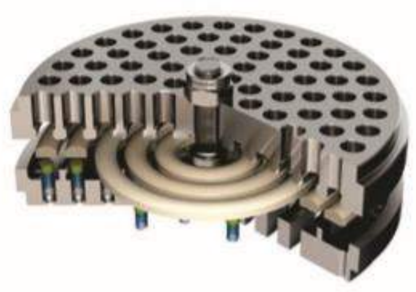

*Ring valve*

*Plate valve*

**Different manufacturers make different type of valves. Major categories are as below:**

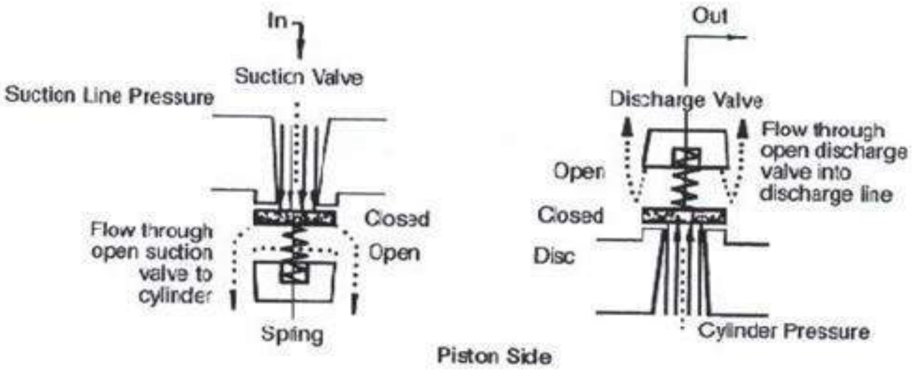
1) Damp plate type valves
2) Channel valves
3) Puppet type Valves
4) Bullet type puppet valves

Under the above categories, further variations are also available under modified categories, which have been developed based on further R&D.

**During maintenance of valve assembly following parts shall be checked carefully for better performance.**

i) Valve seats,
ii) Valve plates
iii) Springs and lift of valve plates in the guard seat
iv) Valve port where the valves are installed over gaskets,

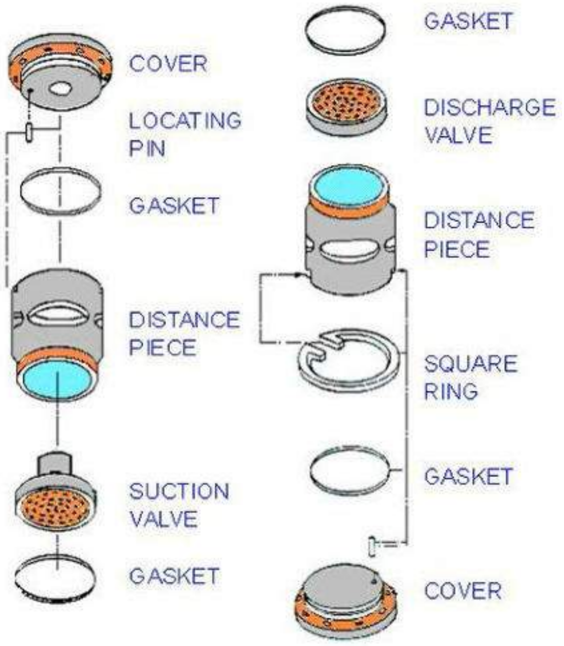
Some times during valve inspection maintenance, valves are found OK but due to pitting or erosion or corrosion on valve seat in the compressor valve port / housing gas by-pass take place giving wrong indication of defective valves.
Sometimes it is also observed that the lift of valve plates in valve assembly is less than the desired lift, in such cases compressor capacity will decreased due to obstruction of flow (hence less flow). Also if the lift of valve plates is more than designed values, the tendency of failure of valve plates will be more.


In
Suction Valve
Suction Line Pressure
Flow through open suction valve to cylinder
Closed
Open
Spring
Piston Side
Out
Discharge Valve
Flow through open discharge valve into discharge line
Open
Closed
Disc
Cylinder Pressure

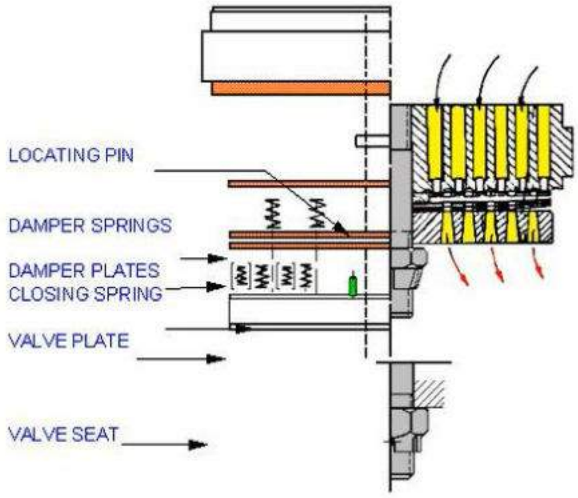
**Actual action of valve plates and springs during suction and discharge and flow of gas**

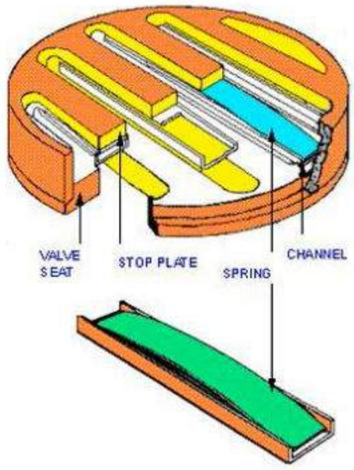
**Poppet type Valves:**

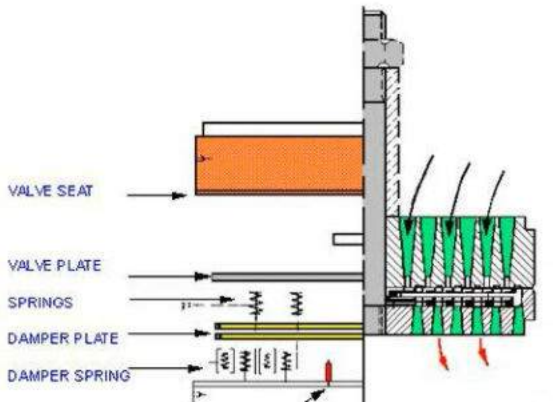
These are very efficient, easy to assemble and cost effective valves. However the presence of condensate in the inlet gas damages these valves badly. The disadvantage of these types of valves is the flow of suction valve damaged puppets to discharge valves making discharge valve also defective. These valves have further been modified by changing the design of puppets to bullet shape. These are also known as bullet valves.

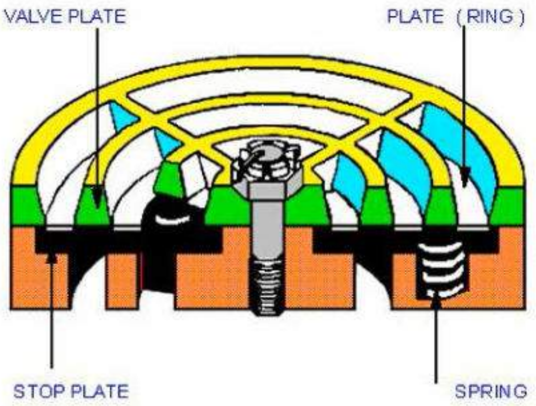

COVER
LOCATING PIN
GASKET
DISTANCE PIECE
SUCTION VALVE
GASKET
GASKET
DISCHARGE VALVE
DISTANCE PIECE
SQUARE RING
GASKET
COVER

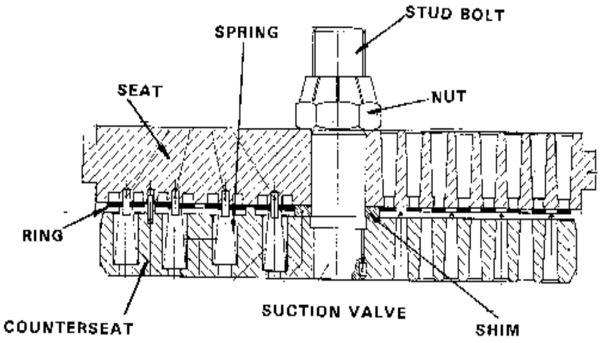
**Suction / discharge valve installation**

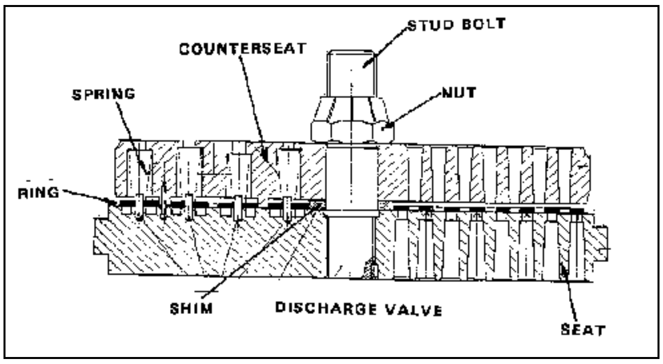

LOCATING PIN
DAMPER SPRINGS
DAMPER PLATES
CLOSING SPRING
VALVE PLATE
VALVE SEAT


VALVE SEAT
STOP PLATE
SPRING
CHANNEL

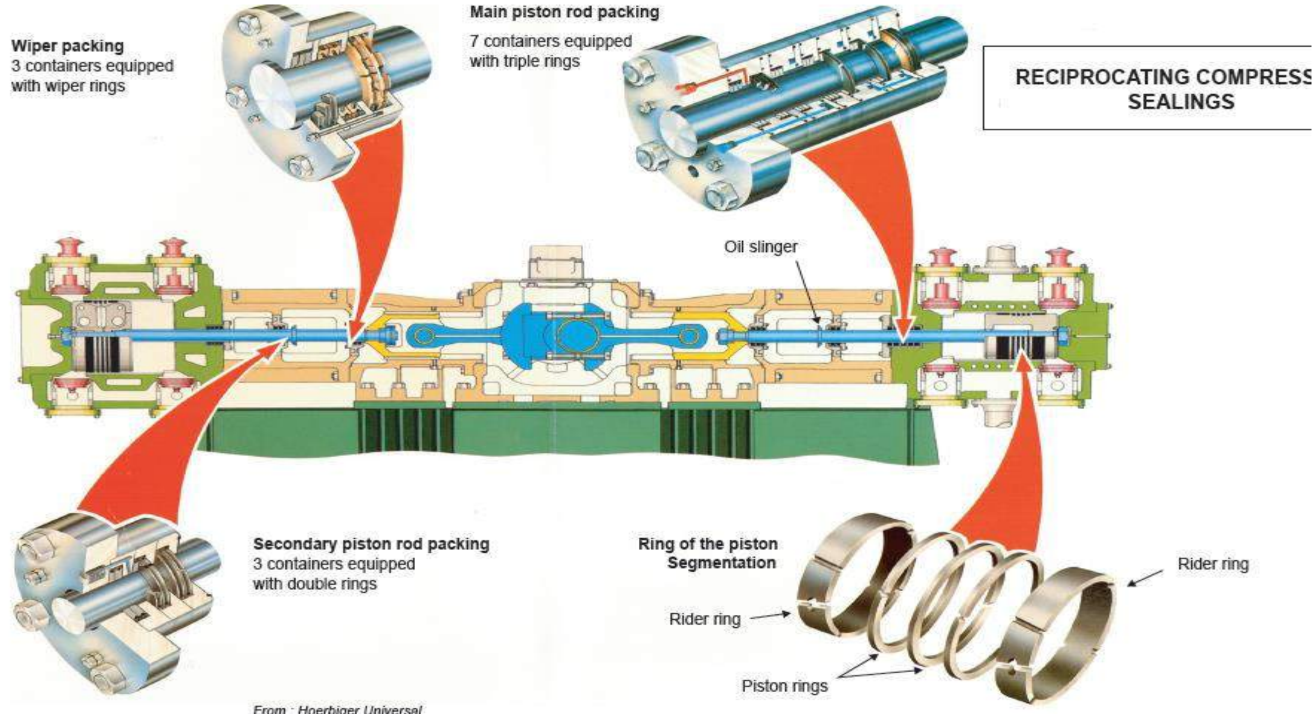

VALVE SEAT
VALVE PLATE
SPRINGS
DAMPER PLATE
DAMPER SPRING


VALVE PLATE
PLATE ( RING )
STOP PLATE
SPRING


STUD BOLT
SPRING
SEAT
NUT
RING
COUNTERSEAT
SUCTION VALVE
SHIM

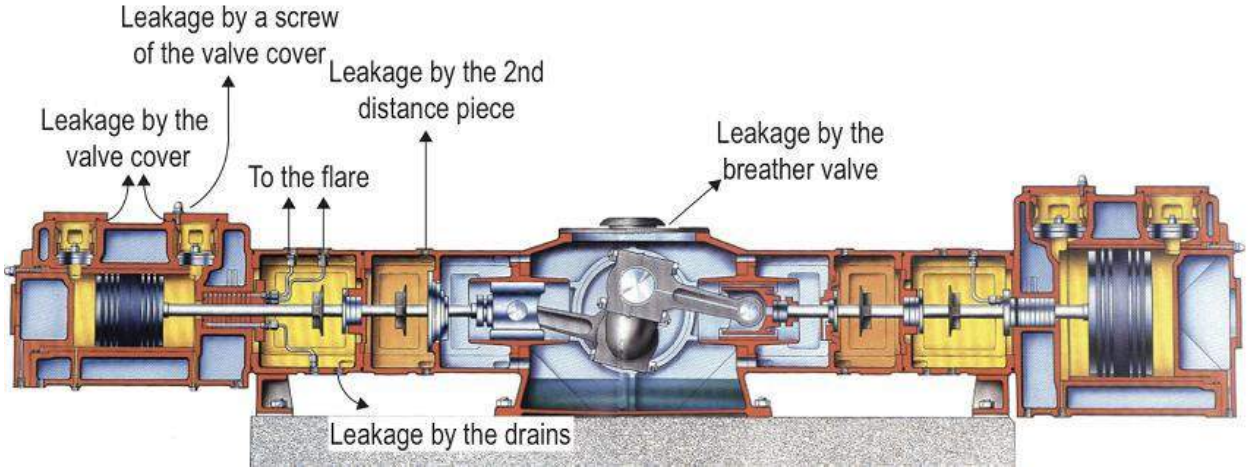

STUD BOLT
COUNTERSEAT
SPRING
NUT
RING
SHIM
DISCHARGE VALVE
SEAT

## RECIPROCATING COMPRESSOR SEALING


Main piston rod packing
7 containers equipped with triple rings
Wiper packing
3 containers equipped with wiper rings
RECIPROCATING COMPRESS SEALINGS
Oil slinger
Secondary piston rod packing
3 containers equipped with double rings
Ring of the piston Segmentation
Rider ring
Rider ring
Piston rings

From : Hoerbiger Universal

## LEAKAGE PATH:


Leakage by a screw of the valve cover
Leakage by the 2nd distance piece
Leakage by the valve cover
To the flare
Leakage by the breather valve
Leakage by the drains

## MAJOR OVERHAULING OF COMPRESSORS:

Major over hauling of big reciprocating compressors are done as per recommendations of manufacturer. **Generally 6 to 8 years interval between two major overhauls is considered to be a good schedule.** During major overhauling of compressor complete machine is stripped off and is assembled back as if new machine is being assembled. Each and every part is marked during the disassembly and is stored at the floor in sequence and cover properly with tag . Measurements are taken and recorded. Measurements are compared with protocols and replacement of parts required is listed out. New parts are also brought to the floor and cleaned thoroughly and again measurement of new parts is also recorded.

Before assembly, crank case level is checked and if required correction is done by changing / modifying sole choke plates. Foundation bolts are tightened and final level readings are recorded.

Main bearings and crank shaft is assembled and clearances of main bearings are recorded. Crank web deflection is recorded. Connected rods are assembled and crank pin bearing, small end bearing and cross heads are assembled. Trueness of connecting rod bore, cross head pin shall be recorded.

Distance pieces with pedestals are assembled and foundation bolts are tightened after leveling.

Cylinder blocks are assembled and piston assemblies are mounted as per procedure. Piston rod deflections shall be recorded and shall be corrected if required.

Alignment of compressor with motor/turbine/gearbox is done and coupling bolts are tightened.

In last cylinder valves are assembled. Through cleaning is done manually and then by dry air and crank case covers are fitted. Lubricating oil is charged in the frame. Compressor freeness is checked by manual baring and then motorized barring is done for some time. In general barring time is recommended by OEM. Finally compressor is run on idling. Loading is done in systematic way as per procedure.

Minor maintenance jobs of the reciprocating compressors are done on as and when required bases during the opportunities.

## Lubrication System of Compressor Cylinders and Packings

**In reciprocating compressor main bearings, big-end bearings, cross head pins etc are lubricated by Gear type or Lobes type Oil pump driven by either directly through crankshaft(directly coupled with the crankshaft)or through separate motors or any prime movers.**

In case of lubricated cylinders and packing separate plunger type lubricators of low pressure or high pressure is used which is driven through cam shaft arrangement and discharge of lubricators is fed into cylinders and packing through non return double ball type check valves. The function of these NRV is to fed lubricating oils into cylinders and to restrict gas coming out.

In normal case if the NRV is functioning OK then the NRV will not become hot but, as soon as NRV started malfunctioning hot discharge gas will back flow through this NRV and it will become hot and it should be replaced immediately as oil will not flow into cylinders which may damage piston rings, cylinder liners, packing etc.

## Material of various components

The material construction of reciprocating compressors plays an important role as if any critical component fails not only equipment will be stopped but serious damages may occur also. During import substitution this material of construction and many other factors should be considered.

**Here given some critical components material of construction:**

**Crank Shaft**: The crank shaft should be forged carbon steel as this transmit rotating power and in some small machines cast iron also used. Forged carbon steel are ASTM 668,AISI 1020,AISI 1045 .

**Connecting Rod**: This should be also forged steel but in some small compressor it may be made of cast steel also

**Piston Rod**: The piston rod is under compression and tensile load constantly. The material of construction is forged steel -i.e.EN41B,AISI 4140,AISI 1037,AISI 420,AISI 410.The surface of the piston rod should be hardened by nitriding, induction hardening and should be polished finished. The hardness shall be minimum 45~55 HRC.As per latest API-618 the surface hardness should be minimum 65 HRC which can be achieved through tungsten carbide coating done through HVOF. The coating should be such that it should not be pilled off during operation

**Piston**: The material of construction of piston can be nodular cast iron, aluminum alloy or steel in case of small bore with higher compression. In case of nodular cast iron ASTM A536, in case of aluminum alloy LM3 and in case of steels ASTM A351.

- For low speed compressors (upto 330 rpm) and medium speed compressors (330-600 rpm), pistons are usually made of cast iron.
- Upto 7” diameter cast iron pistons are made of solids. Those of more than 7” diameters are usually hollow (to reduce cost).
- Carbon pistons are sometimes used for compressing oxygen and other gases that must be kept free of lubricant.
- As the compressor reaches operating temperature, the piston and rod expand more than liner/cylinder does. In order to prevent seizure adequate clearance should be provided, at the same time clearance must be close enough to permit adequate support of piston rings. Similarly end clearance is also important.
- A cold piston is usually installed with one third of its end clearance on the crank end and two third of its end clearance on the head end.

**Cylinder Liner**: Cylinder liner should be grey cast iron with alloy ASTM A 278 and hardness shall not be less than 200 BHN. In case of very high pressure hardened cast steel may be used.

Piston reciprocates inside a cylinder. To provide for reduced reconditioning cost, the cylinder may be fitted with a liner or sleeve. A cylinder or liner usually wears at the points where the piston rings rub against it. Because of the weight of the piston, wear is usually greater at the bottom of a horizontal cylinder. A cylinder liner is usually counter bored near the ends of the outer ring travel i.e. counter bores are made just ahead of the points where the end piston rings stop and reverse direction. Shoulders may form in the liner where the ring’s travel stops unless counter bores are provided.

**Packing Cups**: Piston rod packing cups shall be of AISI-410 forged or from bar stock. The piston rod packing cup face should be lapped and surface hardness should be 35~40 HRC.

**Piston Rings & Rider Rings**: The material of construction of piston rings/rider rings may be Bronze or Cast iron in case of metallic piston rings and filled PTFE(Carbon filled, Graphite filled, Bronze filled, Ceramic filled, Glass filled etc)PEEK,Polymide etc in case of non-metallic. The MOC depends upon the service and application and sometimes it also depends upon the OEM and end users.

- Piston rings provide a seal that prevents or minimizes leakage through piston and liner. Metal piston rings are made either in one piece, with a gap or in several segments. Gaps in the rings allow them to move out or expand as the compressor reaches operating temperature. Rings of heavy piston are sometimes given bronze, Babbitt or Teflon expanders or riders. Lubrication is a must for metallic rings. Teflon rings with Teflon rider bands are sometimes used to support the piston when the gas do not permit use of a lubricant.

**Main Bearing and Big End Bearings**: The material of big end bearing and main bearings shell is of carbon steel or steel and the bearing lining shall be White metal of tin base or lead base or of tri-metal. The white metal lining is of WJ-3 standards

**Cross Head Pin**: The material of construction of cross head pin shall be forged steel.

Small End Bearing/Cross Head Bushing: The material of construction of cross head bushing may be of bronze or aluminum alloy or white metal lined

**Valve seat and Guards**: The material of construction of valve seal and guards shall be cast steel in case of low pressure cylinders and in case of high pressure cylinders material shall be forged steel AISI-410 or cast stainless steel of 316.The valve seat should be lapped and hardness shall be 40~45 HRC.

**Valve Plates**: The material of valve plate may be AISI-410 from bar stock with 13% chromium or PEEK in case of non metallic. The valve plate should be hardened and should be flat.

**Valve Springs**: The material of valve springs may be Spring steel, Inconel alloy ,Hastalloy or 17-4 PH depending upon the pressure and application.

**Studs and Bolting material**: All studs and bolting material shall be alloy steel of ASTM A193 and in case of non critical services carbon steel.

**PEEK --Poly Ether Ether Ketone**

**If the manufacturer's clearance data are not available for clearance measurement, following may be used as guide and rules of thumb.**

1) Piston (cast iron ) to cylinder bore or linear - 0.00125” per inch of bore diameter
   Exmp : 20”cylinder diameter – 20 x 0.00125”=0.025” clearance
2) Piston (aluminium) to cylinder bore or linear -0.003” per inch bore diameter
3) Main bearing and cranks pin bearing to journal clearance
   a) Cast iron or steel backed shell -0.00075” per inch of journal diameter.
   b) Aluminium bearing shell – 0.001” – 0.0015” per inch of journal diameter
4) Crosshead pin to crosshead bushing clearance – 0.0005” – 0.0015” per inch of pin diameter.
5) Cross head pin to cross head clearance – 0.0005” – 0.002” per inch of pin diameter.
6) Crosshead to crosshead guide clearance – 0.00075”-0.001” per inch of cross head diameter.
7) Piston ring end gap
   A) Cast iron -0.003” per inch of cylinder diameter.
   B) Carbon -0.003” per inch of cylinder diameter.
   C) Bronze -0.004” per inch of cylinder diameter
   D) Teflon -0.024” per inch of cylinder diameter
   E) Phenolic-0.005” per inch of cylinder diameter
8) Piston ring side clearance ( average )
   A ) Cast iron -0.003”to 0.004” per inch of ring width
   B )Carbon -0.003” per inch of ring width
   C ) Bronze -0.004” per inch of ring width
   D )Teflon -0.010” per inch of ring width
   E ) Phenolic-0.015” per inch of ring width
9) Minimum clearance between rider ring and cylinder bore in middle of piston adjacent to piston rings.
   a) Cast iron piston -0.00125” -0.0015” per inch of cylinder diameter.
   b) aluminium piston -0.002” per inch of cylinder diameter

**Estimating clearances by calculating thermal expansion:**

Formula: L = (Q X T X L) + 20 %
Where – Q – 0.000006” per inch per degree faranhit (co efficient of expansion of cast iron or steel )
**Exmp 1** : cross head to cross head guide clearance
Cross head diameter – 8.5 “
T = 75 F(AMBIENT) to 170 F =95 F
L=(0.000006 X 95 X 8.5 ) X 1.2 = 0.006”
**Exmp 2 :** Piston to cylinder bore clearance
Piston diameter - 20 “
Discharge temp – 280 F
Ambient temp -80 F
Material of piston – cast iron.
T = 75 F (AMBIENT) to 170 F =95 F
L= (0.000006 X (280-80) X 20) X 1.2 = 0.029”

## Few Terms for Reciprocating Compressors

### Jacket Cooling

Jacket cooling of a cylinder is done to remove the heat of friction that the moving piston generated inside the cylinder. This cooling also reduces the work done by the machine. Cooling water is used for cooling the jacket

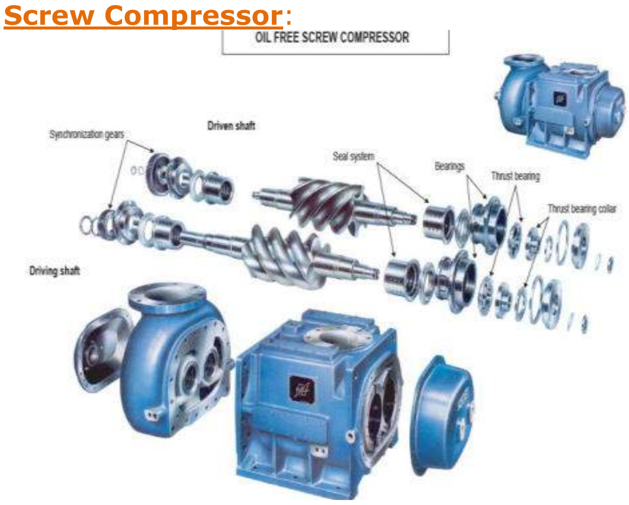
### Dampeners

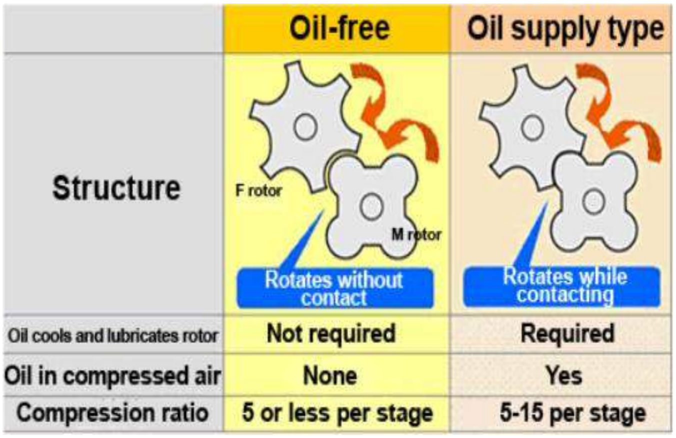
A reciprocating machine delivers the fluid at a pulsating rate. To remove this pulsation, surge drums/pots are provided at the suction and discharge of the stages. This extra volume compensate for the pulsating flow. These drums/pots are called Dampeners

### Knock Out Pots /drum

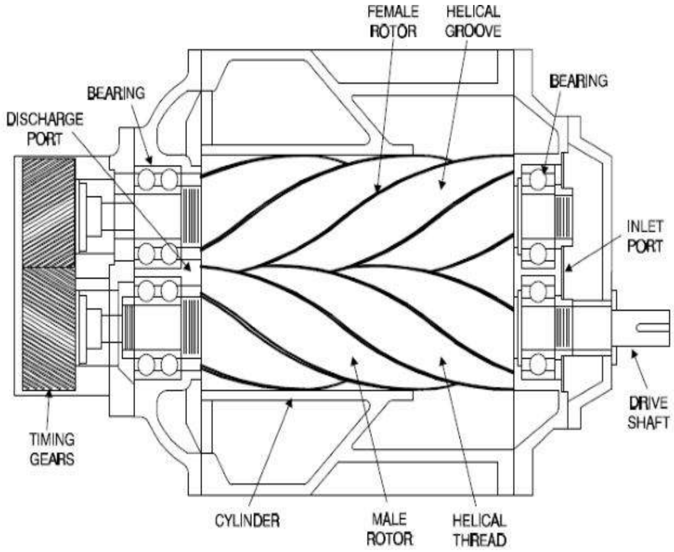
To remove the condensate from the gas when it cooled, pots are provided in suction of the stages which do not allow the liquid to go to the machine stages thereby avoid damage to the machine

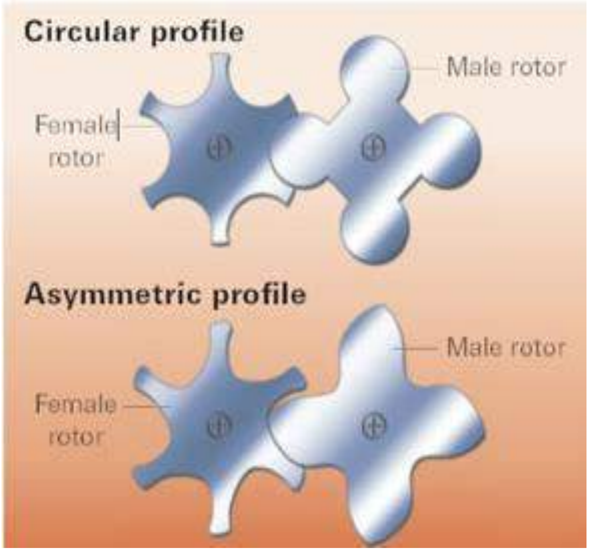
## Screw Compressor:


OIL FREE SCREW COMPRESSOR
Synchronization gears
Driven shaft
Seal system
Bearings
Thrust bearing
Thrust bearing collar
Driving shaft

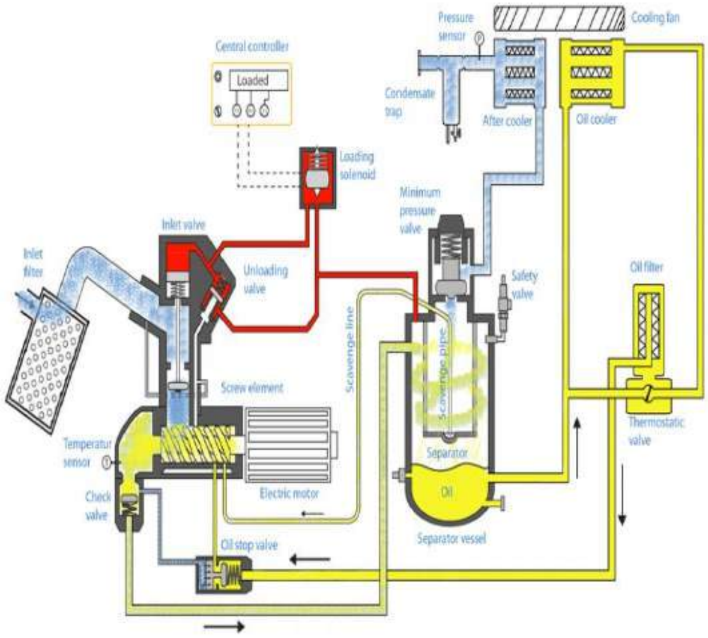


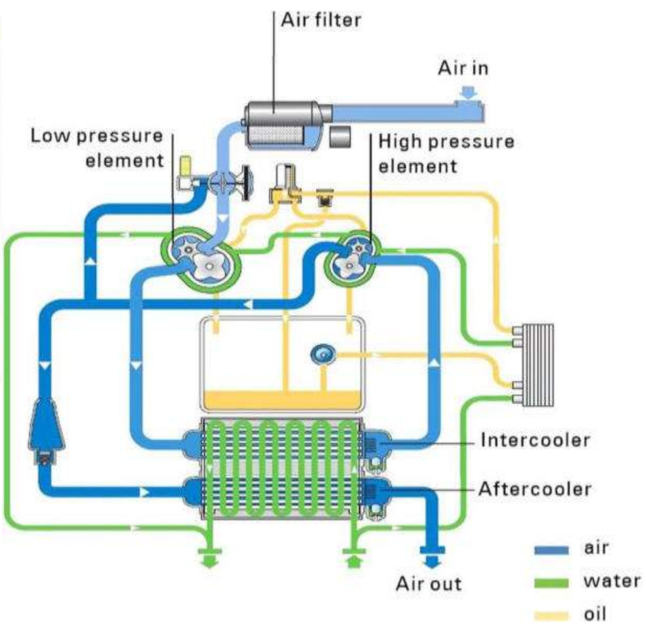
| | Oil-free | Oil supply type |
|---|---|---|
| Structure | F rotor<br>M rotor<br>Rotates without contact | Rotates while contacting |
| Oil cools and lubricates rotor | Not required | Required |
| Oil in compressed air | None | Yes |
| Compression ratio | 5 or less per stage | 5-15 per stage |


FEMALE ROTOR
HELICAL GROOVE
BEARING
DISCHARGE PORT
BEARING
INLET PORT
DRIVE SHAFT
TIMING GEARS
CYLINDER
MALE ROTOR
HELICAL THREAD


Circular profile
Male rotor
Female rotor
Asymmetric profile
Male rotor
Female rotor

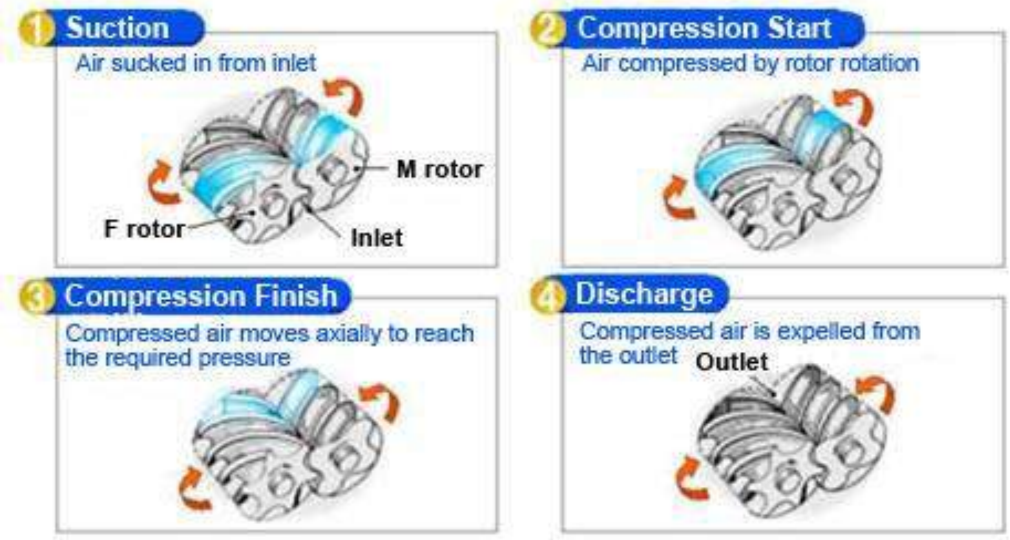
### Oil lubricated screw compressor:


Pressure sensor
Cooling fan
Central controller
Loaded
Condensate trap
After cooler
Oil cooler
Loading solenoid
Minimum pressure valve
Inlet valve
Inlet filter
Unloading valve
Safety valve
Oil filter
Scavenge line
Scavenge pipe
Screw element
Temperatur sensor
Separator
Thermostatic valve
Oil
Check valve
Electric motor
Oil stop valve
Separator vessel


Air filter
Air in
Low pressure element
High pressure element
Intercooler
Aftercooler
Air out
air
water
oil

Screw compressors are rotary positive displacement type compressor. This type of compressor employs a rotating action to compress and eject the entrapped gas. Screw Compressor consists of two mating, helically grooved rotors set, positioned in bearing at either end of the compressor casing. The rotor, which has generally four to six convex lobes is called the male rotor and the mating rotor having five or six concave lobes is called female rotor. The lobes profile is of special design having an unsymmetrical profile which gives high compression efficiency. Generally Rotors are forced lubricated type to avoid wear and the leading edges do not come in contact with the casing as there is some clearance maintained between rotor edges and compressor casing. Non lubricated screw compressors are also common.

**The length and diameter of the rotors determine the capacity and the discharge pressure. The larger the diameter the greater the capacity and longer the rotors, the higher the pressure.**


1 Suction
Air sucked in from inlet
M rotor
F rotor
Inlet
2 Compression Start
Air compressed by rotor rotation
3 Compression Finish
Compressed air moves axially to reach the required pressure
4 Discharge
Compressed air is expelled from the outlet
Outlet

The screw compressor are fitted with Mechanical seal of Conventional seal , Bellow type seal or Dry gas seal to prevent gas leakages from the drive shaft.

**Suction phase**: The pair of lobes unmesh on the suction port side creating space for the gas to occupy. Gas flows in the increasing volume formed between the lobes and the casing until the lobes are completely unmeshed.

**Transfer phase**: The trapped pocket of gas isolated from the inlet and outlet ports is moved circumferentially within the screws at constant suction pressure.

**Compression phase**: When re-meshing starts at the inlet, the trapped volume of gas starts reducing and the gas is gradually moved helically along the screw profile, while simultaneously being compressed towards the discharge end as the lobes mesh points moves along axially.

**Discharge phase**: Discharge starts when the compressed volume has been moved to the axial ports on the discharge end of the compressor and continues until all the trapped gas is completely purged in the discharge port.

**Bearings**: **A sleeve type white metal lined bearings are generally used for main journal bearings. These bearings receive radial loads only.**

Great amount of thrust load comes in the screw compressors. Individual thrust bearings (Thrust ball bearing or Thrust pad bearing) receives the axial loads of male and female rotors which results from the pressure of the gas and the interaction of the drive load and the helical configuration of the rotors. Thrust bearings are of very high importance in screw compressors.

**Balance Piston:**

During operation of the compressor, the male rotor runs with much high speed than the female rotor and so the thrust of male rotor is higher than female rotor. To compensate this extra thrust of male rotor a **balance piston is provided on the male rotor** and oil pressure is given to the balance piston from the opposite side of driving axial and to balance the axial load. Some compressors have balance piston on male rotor only and while some compressor may have balance piston on both the rotors but of different diameters depending upon the axial thrust. The balance piston can be mounted on either side, discharge end or suction end. Accordingly the direction of oil pressure on the balance piston is set in the casing.

## Running Clearances of Screw Compressor

Generally the running clearances of journal bearing is 1 thou(0.001”) per inch diameter of journal but, different OEM recommends their own running clearances according to RPM, Oil viscosity and applications. **Below given of some OEM running clearances**.

Diameter Clearance of Journal Bearing = 0.13~0.16 mm
Diameter Clearance of Balance Piston to Ring =0.04~0.12 mm
Rotor Discharge End Clearance =0.10~0.15 mm (When rotor push to suction side)
Rotor Suction End Clearance =0.55~0.72 mm

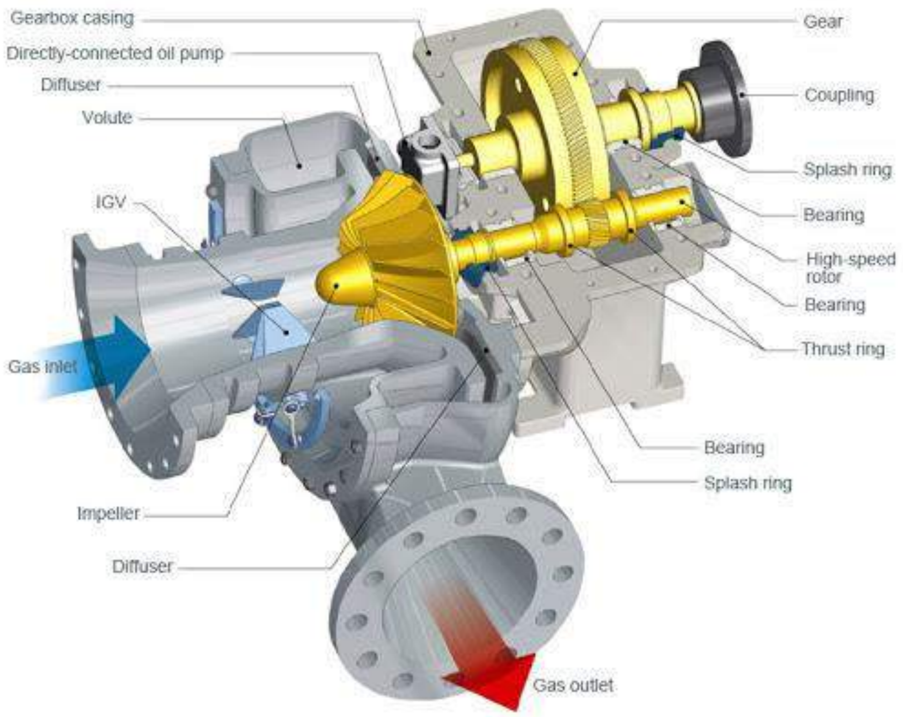
**The clearance between Rotor pair is 0.003” and the clearance between rotor set and casing is 0.005”.**

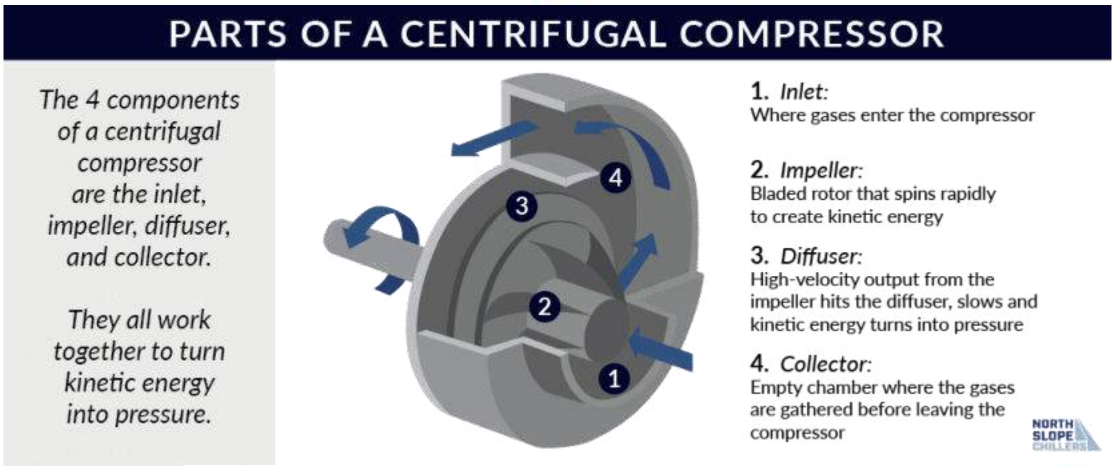
**Normal PM of compressor**: follow OEM recommendation but check & replace if required…
Air filter, oil filter, oil replace, check loading / unloading valve, check cooler or clean and safety device

**Compressor Comparisons**

| Reciprocating | Rotary Screw |
|---|---|
| • Cost advantage as a single-acting, air cooled unit below 30 hp.<br>• Double-acting units used above 250 psig and in non-lubricated applications.<br>• Normally used for heavy-duty, continuous service.<br>• High overall efficiency.<br>• Operates efficiently at partial loads.<br>• Saves horsepower in no-load conditions.<br>• High initial and maintenance costs.<br>• Large sizes require heavy foundations. | • Used more in 150 psig, lubricated air systems above 30 hp.<br>• Used for constant-volume, variable-pressure applications.<br>• Oil or water is used for sealing and cooling.<br>• Must vent reservoir to lower power consumption when unloaded.<br>• Delivers high air volume in a compact space.<br>• Smooth, pulse-free output.<br>• Easy to install and maintain.<br>• Low vibration. |

## CENTRIFUGAL COMPRESSOR:


Gearbox casing
Directly-connected oil pump
Diffuser
Volute
IGV
Gas inlet
Impeller
Diffuser
Gear
Coupling
Splash ring
Bearing
High-speed rotor
Bearing
Thrust ring
Bearing
Splash ring
Gas outlet



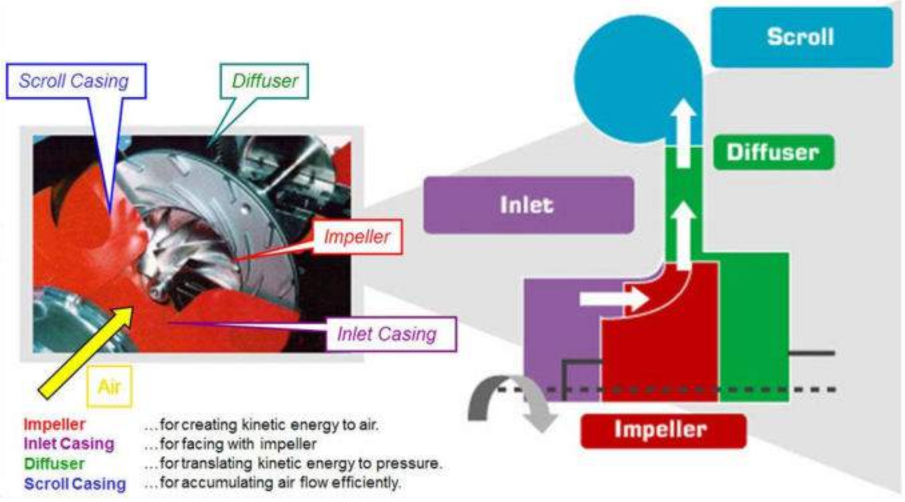
PARTS OF A CENTRIFUGAL COMPRESSOR

*The 4 components of a centrifugal compressor are the inlet, impeller, diffuser, and collector.*

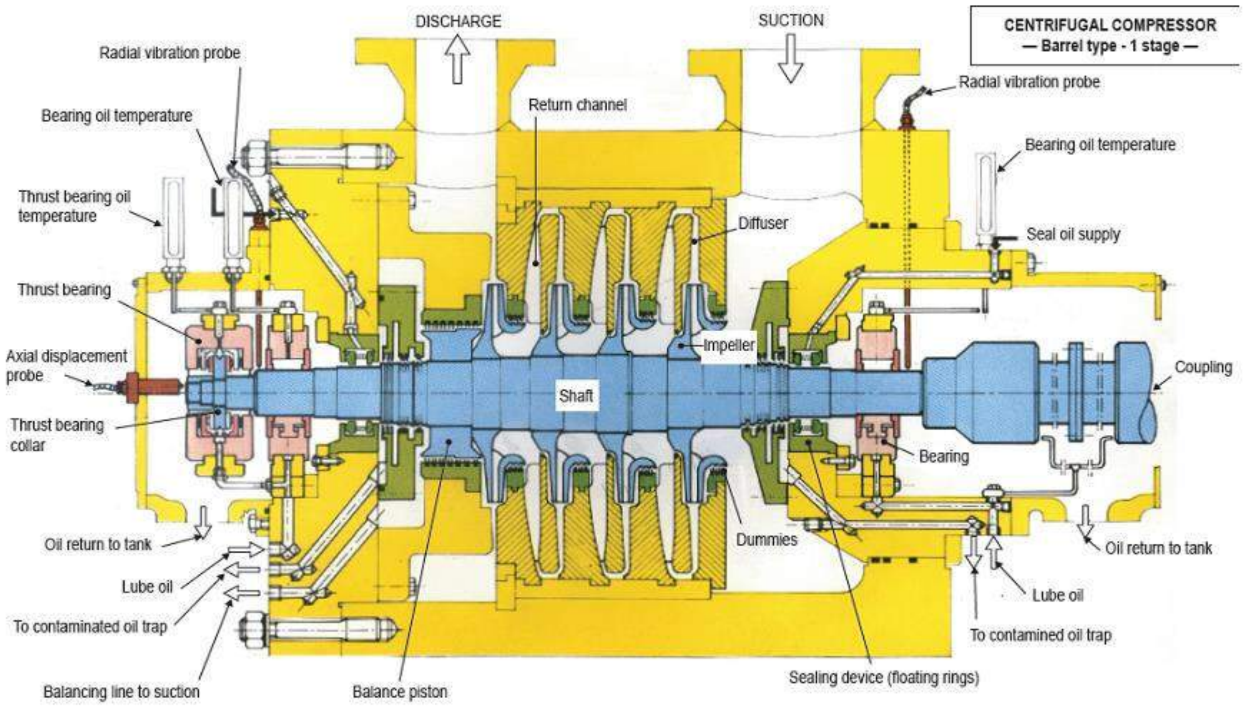
*They all work together to turn kinetic energy into pressure.*

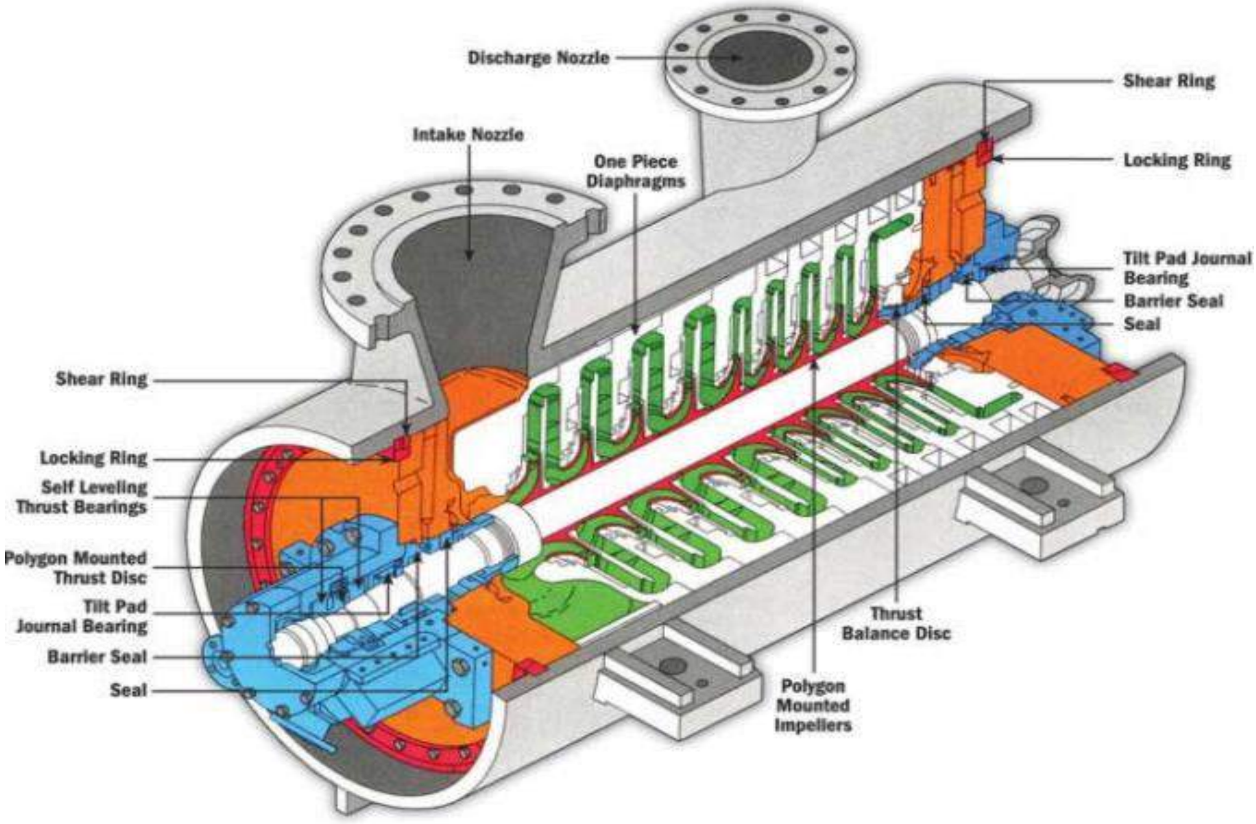
1. *Inlet:* Where gases enter the compressor
2. *Impeller:* Bladed rotor that spins rapidly to create kinetic energy
3. *Diffuser:* High-velocity output from the impeller hits the diffuser, slows and kinetic energy turns into pressure
4. *Collector:* Empty chamber where the gases are gathered before leaving the compressor

1
2
3
4
NORTH SLOPE CHILLERS


Scroll Casing
Diffuser
Impeller
Inlet Casing
Air
Scroll
Diffuser
Inlet
Impeller

Impeller ...for creating kinetic energy to air.
Inlet Casing ...for facing with impeller
Diffuser ...for translating kinetic energy to pressure.
Scroll Casing ...for accumulating air flow efficiently.


CENTRIFUGAL COMPRESSOR
— Barrel type - 1 stage —
DISCHARGE
SUCTION
Radial vibration probe
Bearing oil temperature
Thrust bearing oil temperature
Thrust bearing
Axial displacement probe
Thrust bearing collar
Oil return to tank
Lube oil
To contaminated oil trap
Balancing line to suction
Balance piston
Return channel
Diffuser
Impeller
Shaft
Dummies
Sealing device (floating rings)
Radial vibration probe
Bearing oil temperature
Seal oil supply
Coupling
Bearing
Oil return to tank
Lube oil
To contamined oil trap


Discharge Nozzle
Intake Nozzle
One Piece Diaphragms
Shear Ring
Locking Ring
Tilt Pad Journal Bearing
Barrier Seal
Seal
Shear Ring
Locking Ring
Self Leveling Thrust Bearings
Polygon Mounted Thrust Disc
Tilt Pad Journal Bearing
Barrier Seal
Seal
Thrust Balance Disc
Polygon Mounted Impellers

Centrifugal compressors are fluid flow dynamic machines for the compression of gases according to the principals of dynamics. The bladed impeller with its continual internal flow serves as an element of energy transfer to the gas.

Pressure, temperature and velocity of the gas leaving the impeller are higher than at the inlet.

Diaphragms or diffusers arranged after the impeller helps in diverting the gas velocity, thus further increase in pressure and temperature is achieved by the conversion of the kinetic energy into pressure energy.

During energy transfer in the impeller, the gas flows from the inside in an outward direction. It is therefore subjected to the change of the centrifugal field, through which the attainable pressure ratios are substantially higher than those of axial compressors.

The radial direction of flow in the impellers again requires radially arranged diffusers, which increases the outer diameters of the casing to about double the impeller diameters.

**Generally centrifugal compressor are used for high capacity and low pressure and though initial cost is high but, lower maintenance and running cost places these compressors to compare with high efficiency reciprocating compressor.** Manufacturing, testing and accessories for Centrifugal compressor for plants are **manufactured according to API 617 code**.

## General construction of centrifugal compressor:

Centrifugal compressors are generally manufactured in two configurations:

1) Horizontally split Construction
2) Barrel type construction

Compressors of both the configurations are in use and the discharge pressure of the gas directs the designs. **Centrifugal compressors are also manufactured in integral gear type construction, which are governed by API 672.**

Centrifugal compressors are composed of outer casing which contains stator part called a diaphragm bundle, a rotor formed by a shaft with one or more impellers, a balance drum, thrust collar etc. The rotor is driven by means of coupling hub and is held in position **radially by journal bearings and axially by a thrust bearing.**

Sealing system in centrifugal compressors is very interesting and a bit complicated. Sealing of by-passing gas from one stage to another is required between all the inter stages and also at both the shaft ends as well. In general rotor and stators are fitted with labyrinth seal rings sealing. In toxic gas services 100% leak-proof seals are required which may be of different type depending on the service of the compressors. **Oil deflectors and oil labyrinths are used as oil seal on both ends of the rotor.**

Gas is drawn into the compressor through suction nozzle of the compressor and enters in to an annular chamber called inlet volute, flowing towards the center of the impeller from all directions in a uniform radial pattern. The rotating impeller imparts energy through its wanes and pushes the fluid outwards raising its velocity (kinetic energy) and pressure as it passes through the impeller shroud. The outlet fluid leaves the impeller tangentially and then enters into another circular chamber called diffuser, where its velocity (kinetic energy) is converted into pressure energy. After this increase in pressure of the fluid in one stage again it enters into second stage impeller eye and cycle goes on till the final discharge of the pressurized gas from the compressor discharge nozzle.

**Horizontally split Construction** Horizontally split casing consists of two halves joined along the center line by casing bolts. These types of compressors are generally made up to 40 kg/cm2 discharge pressure. All the suction nozzle, discharge nozzle, lubricating lines and other connections are generally located in the lower half casing so that during maintenance / inspection, only the upper half casing can be removed easily and gain access to all internal components. The material of construction of casing depends upon the operating parameters like pressure, temperature, gas handled etc. **API 617** governs this selection. Generally used material is meehanite grade cast iron, ASTM A216 WCA and ASTM A 351 Gr.CA15 steel in case of corrosive fluid.

**Barrel type construction**

Axially split design is more suitable for high pressure services. Above 40 kg/cm2 discharge pressure this type of design is more common. The Outer casing is generally in form of a barrel which is closed by end cover. Internal casing may again be made in two designs called Axial split or horizontally split. Both types of designs are approved in API 617. Barrel casing may be designed with one side end cover of with both side end covers. Generally one side end cover design is more common and acceptable.

Material of construction of barrel and end covers is generally Forged carbon steel as per ASTM A105, however, forged alloy steel are also used depending on design requirements. Material of construction of internal casing depends on the design parameters however in general martensitic Stainless Steel is used.

**Rotor**:

**The rotor of a centrifugal compressor consists of shaft, impellers, balancing device, thrust bearing collar, coupling hub, end seals, sleeves and spacer rings.**

The material of **construction of shaft** may vary from forged plane are carbon steel to forged low alloy steel to forged martensitic stainless steel. Material shall be suitable for hardening and tempering so that toughness can be enhanced. Generally used grades are EN series grades 8, 9, 19, 24 and 56. Forged allow steels like SAE 4140, 4340 etc.

Material of **construction of Impellers** may vary from cast iron to stainless steel depending upon the design parameters and the economics of the machine. When Impellers are used in corrosive services, steel with higher chromium content is used. For higher strength and corrosive service Maraging (Manufacturer's standard) steel is used. In old machines generally cast impellers were used. Then riveted impellers were very famous as the degree of freedom in manufacturing had enhanced the capabilities for making narrow and efficient impellers. As the demand for high pressure and small machines increased, welded impellers replaced the riveted impellers. Now a day, **electron brazed impellers and electron beam welded impellers are famous for their quality and efficiencies**. With improving technology, impeller design has improved from simple impeller to 3D impeller which has enhanced the compressor efficiencies many folds.

There are different levels of **sealing systems** required for centrifugal compressors. The end shaft seals, inter stage seals, balancing device seal, oil seals etc. Depending on the service, end shaft seals are selected based on the toxicity of the gas to be handled. As per API 617, all toxic gas shall be sealed positively without polluting surrounding atmosphere. Positive seals are Mechanical seals which have been designed specifically for the high speed high pressure compressors. These may be pure mechanical seal with suitable mating seal combination, or gas seal or Entrapped oil dynamic seal which have been designed by different manufacturers.

**For Non Toxic services Labyrinth seal are most common seal used in centrifugal compressors**. Labyrinth seal design is again specific with different manufacturers however the principal of working is same. In side high pressure is allowed to let down successively in series of labyrinth rings so that very minimum gas pressure is generated in the outermost ring which discharges the gas to atmosphere. The sealing system is very simple, cost effective, but it is not positive sealing system.

Similarly due to difference in pressure rise across successive compression stages, to avoid the bypassing seals are provided at the impeller suction eye, impellers' rear end and the corresponding surfaces of diffusers. The condition of these seals directly affects the compressor performance.

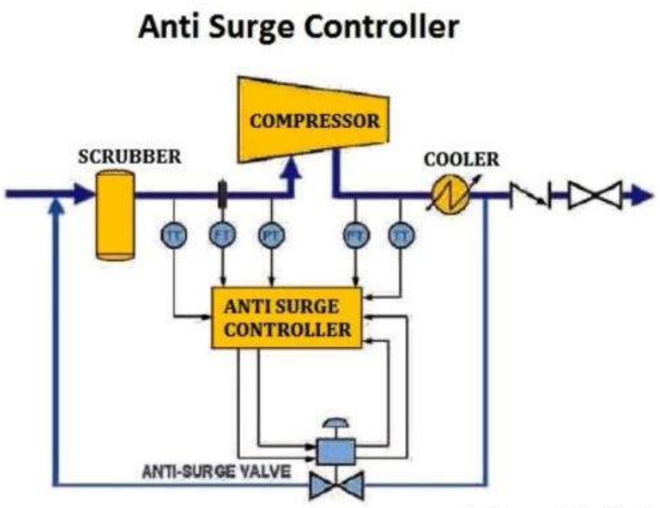
The material of **construction of labyrinth** seals should be resistant to corrosion and erosion. Generally used material for labyrinth seals are annealed aluminum alloy, stainless steel, bronze, babbit and martensitic stainless steels.

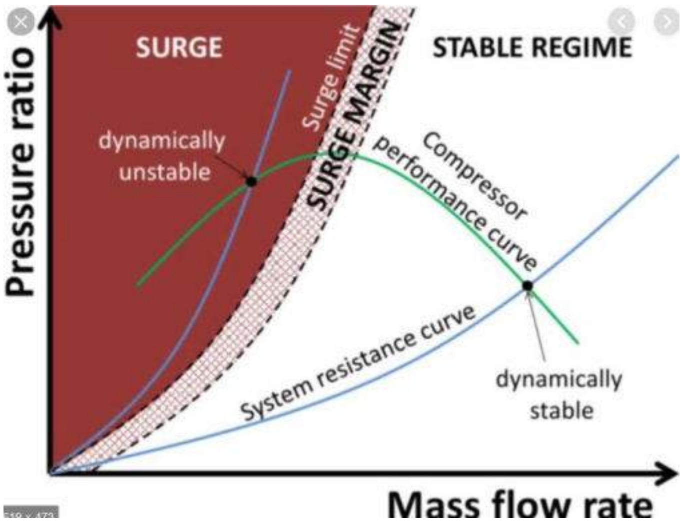
**Diffusers:**

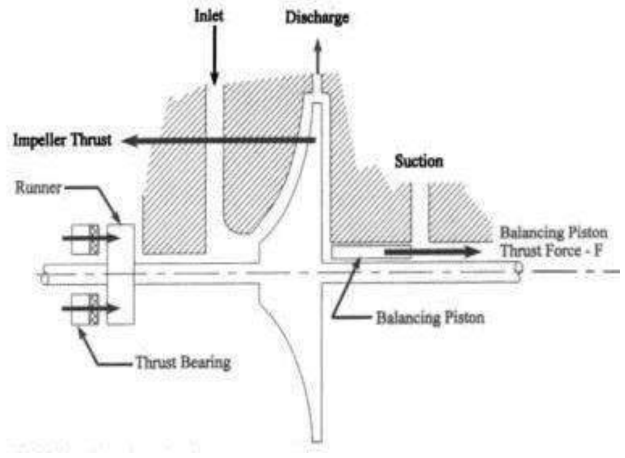
In centrifugal compressors, the discharged gas from impellers enters into diffusers. **The diffuser not only guides the gas to next stage but also helps in regaining pressure from the velocity of the gas**. Since velocities are very high through the diffuser, surface finish and friction factor is very crucial for overall efficiency of the compressor. Centrifugal compressor losses their efficiencies in diffusers only. In many process services dirt or other inclusions gets stick to impeller and diffuser and fowling will not only narrow down the openings but also produce rough surface area in the fluid passages which can reduce the overall efficiency of the compressor drastically. Material of **construction of diffusers** is generally cast iron, cast steels or cast stainless steels.

**Surge –**

The term surge indicates a phenomenon of instability which takes place at low flow values and normally occurs at about 50% of design inlet capacity at design speed. It is a point on the operation curve of the compressor at which the compressor cannot add enough energy to overcome the system resistance. This causes a rapid flow reversal (i.e. surge). As a result, high vibration, temperature increases and rapid changes in axial thrust can occur. These cyclic occurrences of this phenomenon can damage the compressor rotor, seals, rotor bearings. Most turbo machines are designed to easily withstand occasional surging and surge control devices have become mandatory for these machines. However, if the turbo machine is forced to surge repeatedly for a long period of time or if the turbo machine is poorly designed, repeated surges can result in a catastrophic failure.







**Compressor rated Speed**

It is the speed of the compressor at which it develops the required pressure at required flow. It is considered as 100% rated speed.

**First Critical speed**

It is the rpm at which the natural frequency of the flexible rotor matches the system speed. This RPM should be crossed rapidly while increasing the speed of the system otherwise abnormal vibrations may set in the machine in this range of speed.(fig-axial thrust) Within the compressor, the suction side of the impeller is partly exposed to suction pressure and partly to discharge pressure however the opposite side of the impeller, the whole area of cross section is exposed to discharge pressure only. This difference of pressure working on impellers creates axial thrust- force in the rotor, which normally acts towards suction side. The total thrust produced by all the impellers is counter balanced by introducing a balance drum or balance disc or combined disc-drum which is mounted on the shaft after the last stage impeller. Rotors shall be designed in such a way that minimum resultant thrust keeps the rotor stable on the active side of the thrust bearings. If the axial thrust of the rotor gets neutralized, rotor will remain floating during the operation.

**Centrifugal V/S Reciprocating Compressors**

Integrally geared centrifugal compressors can operate at many times higher speeds than reciprocating compressors. The higher speeds ultimately result in smaller package sizes as compared to a reciprocating compressor. The operating speed of a reciprocating compressor is very slow due to mechanical and dynamic limitations.

Higher reliability is fully attainable with centrifugal compressors. The rotating aerodynamic components (impellers) have no physical contact with the stationary parts (inlet shroud). On the contrary, in the reciprocating compressor moving components such as the piston, cross head, connecting rod, piston rod etc. are having relative movement with each other. Similarly inlet and outlet valves are having parts having relative movement and physically in contact with each other. The physical contact and relative movement causes wear and tear of both moving and stationary components, which requires frequent and regular maintenance. However a centrifugal compressor operates for many years with continuous service without overhaul maintenance resulting in less plant down time. This eliminates loss of product, provides more profit, lowers risk, and results in lower maintenance cost.

Considering there is no physical contact between the centrifugal compressor rotodynamic components, except for the bearing lubrication, the need for lubrication within the compressor components is not required; thus it will not add oil or other contaminants to the process gas. However, a reciprocating compressor requires oil lubricant for the piston rings and other moving parts. This oil eventually ends up in the process gas or it has to be separated to get the oil free gas.

The dynamic loads placed on a centrifugal compressor foundation would typically be in the order of 10-lbf (44.5 N) as compared to 400-lbf. (1780 N)for a reciprocating compressor, in a similar services. The dynamic load is proportional to the unbalance weight and square of the speed; therefore, despite low operating speed the dynamic load is still very high on the foundation of the reciprocating machines.

Furthermore, the lower speed of reciprocating compressor lends itself to larger compressor size, heavier weight, and larger plot plan size. Whereas the centrifugal compressor with higher operating speeds results in smaller overall compressor package sizes such as smaller gearing, bearings, seals, lubrication system and foundation. Smaller packages ultimately lend themselves to saving in lower overall installations as well as lower capital and spare parts costs.

## Inter-cooling

When a gas is compressed then work is done on the gas and therefore its temperature increases. This rise in the temperature of the gas has a number of disadvantages. They are:

1. Volume of the gas increases with the increase in temperature and energy required to compress per kg of the gas is larger than if the compression were isothermal (i.e. when the compressed gas inlet and outlet temperatures remain same).
2. Excessive temperature of compressed gas leads to problems with lubricants, stuffing boxes and material of construction.
3. The gas may not tolerate high temperatures i.e. it may decompose.

## Compression Ratio

The compression ratio (R) is defined as the ratio of compressor absolute discharge pressure to absolute suction pressure. -i.e. Compression ratio (R) = Absolute discharge pressure /absolute suction pressure .If the compression ratio is high, the temperature of the discharged gas becomes high. Also, the heat generated due to friction during compression gets added to this. In order to remove this heat, compressors such as reciprocating ones are cooled by jackets through which normally, cold water is circulated. Also, at compression ratios above 5.0, the gas is compressed in more than one stage. After each stage of compression, heat of compression is removed by circulating through inter stage coolers before proceeding to next stage of compression. The inter cooling not only reduces gas temperature and volume of the gas but also reduces the horsepower required for compression. Number of Stages, A compression ratio of 3.5 to 4.0 per stage is considered maximum for normal process operations. A higher compression ratio per stage means a higher temperature rise per stage. This temperature rise is a limiting factor for higher compression ratio. Therefore more than one stage is used for compressing gas to very high pressures Horsepower or energy required for compression will be a minimum if the compression ratio of all the stages is equal in a multistage compressor.

**Compression ratio is pure number without any units**.

## Surge Phenomena' In Centrifugal Compressors

The operation of a centrifugal compressor becomes unsuitable below a certain minimum capacity. This is because of a phenomenon called as surging which takes place below a certain minimum capacity operation of the compressor. In the normal operation of a Centrifugal Compressor, the discharge valve remains fully open. Suppose if we throttle (slightly close) the discharges valve, the system resistance or back pressure to the compressor discharge flow increases.

To overcome this resistance, the head required by the compressor must increase. As the throttling of discharge valves is continued, gas flow through the compressor will become less and less. This continues up to the point of maximum head capability of the compressor. If the system resistance still continues to increase than at this point **a reverse flow of gas from system to compressor will take place the system back pressure exceeds that capable of the compressor delivery causing a momentary back flow condition.**

When this back flow occurs, the system resistance or back pressure gets lowered and makes the compressor capable of delivering flow higher than when back flow or surge began. Now if the discharge valve condition remains the same, very soon the flow will drop below the surge limit causing another back flow. **This cycle of repeated flow reversal, as the compressor alternately tries to deliver gas and the system returning it is called as 'Surging'.** Surge may be caused by a system disturbance or insufficient suction flow.

## Effects of Surge

Surge is the most undesirable phenomena that need to be taken care of or guarded from in Centrifugal Compressors/Blowers/Fans .Severe, unimaginable damages have occurred on machines due to this.

This is a phenomenon similar to cavitations in Pumps.

Following types of damage can occur if Surge is allowed to occur:

1. Due to repeated reversal of flow, the **vibrations and the axial displacement** of the Compressor may increase. This may develop stresses and strains in the shaft of the compressor or may lead to its permanent distortion.
2. Vibration in the compressor may **damage the shaft bearings**.
3. The compression heat may damage heat sensitive parts such **as labyrinth seals** of the compressor due to erratic flow through the compressor.

4. **Damage to the Installations** on/around the compressor like Valves, Instruments, piping supports etc.

## Surge Prevention

As a thumb rule, a centrifugal compressor surges when its capacity is reduced to around 60% of design flow and its head exceeds 115% of design. Surging of the compressor can be avoided by avoiding this condition of operation. **Normally a centrifugal compressor is provided with an anti surge control to prevent surging condition of the compressor during normal operation of the plant. The most common method is to bypass the discharge flow back to suction through a control valve, which is called as Anti-surge valve.**

## Dry Gas Seals:

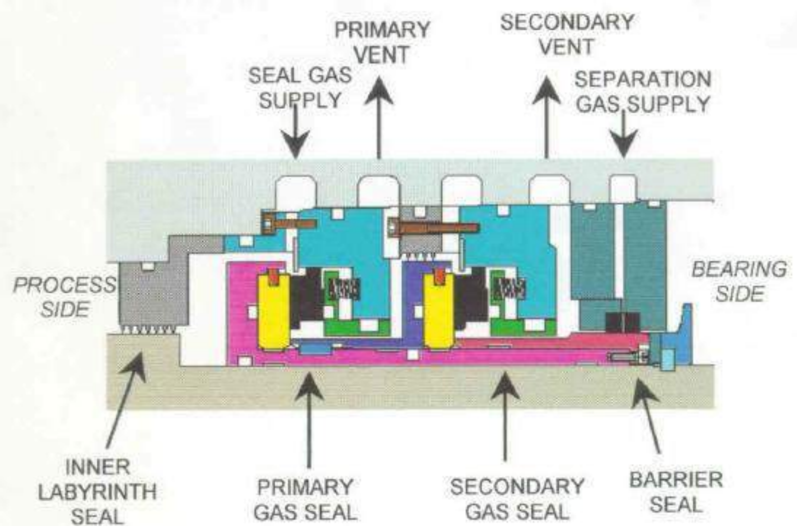
### Design, Operation and Maintenance Consideration for Improved dry Gas Seal Reliability in Centrifugal Compressors

Centrifugal compressors in process gas service require shaft sealing to prevent the process gas from escaping the compressor case uncontrolled, into the atmosphere. Multistage, “beam” style compressor two seals, one at each end of the shaft. Single stage,” overhung” style compressor require a single shaft seal, directly behind the impeller. Dry gas seal can be applied to accomplish the required shaft sealing. Contamination is a leading cause of dry gas seal degradation and reduced reliability

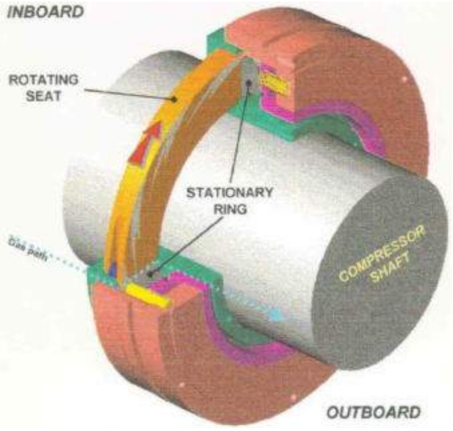
Dry gas seal are available in variety of configurations, but the “tandem” style seal is typically applied in process gas service. Tandem, seals consist of a primary seals and a secondary seal, contained within a single cartridge. During the normal operation, the primary seal absorbs the total pressure drop to a vent system, and the secondary seal acts as a backup should the primary seal fail.

**Dry gas seal are basically mechanical face seals, consisting of a mating (rotating) ring and a primary (stationary) ring. During operation, grooves in the mating ring generate a fluid-dynamic force causing the primary ring separate from the mating ring creating a “running gap” between the two rings. A sealing gas is injected into the seal, providing the working fluid for the running gap and the seal between the atmosphere or flare system and the compressor internal process gas.**

Inboard of the dry gas seal is an inner labyrinth seal, which separates the process gas from the gas seal. Outboard of the dry gas seal is a barrier seal, which separates the gas seal from the compressor shaft bearings



**Typical Tandem Gas Seal/ Barrier Seal Configuration**



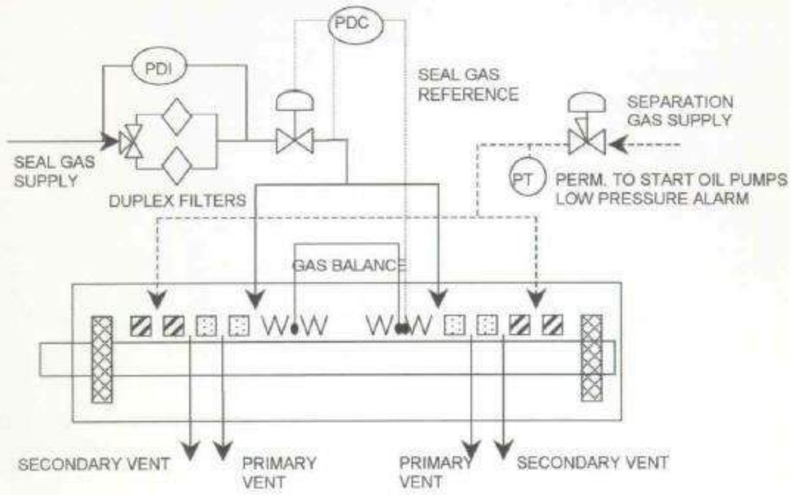
**MATING RING SEAL GROOVE**

**GAS SEAL COMPONENT**

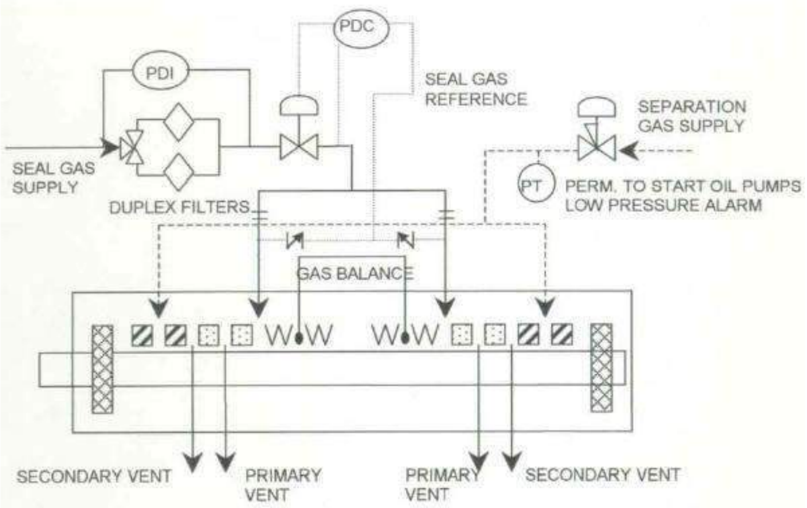
### Dry Gas Seal Systems

The use of dry gas seals requires a system designed to supply sealing gas to the seal as a sealing and working fluid for the running gap. These gas seal systems are normally supplied by the compressor OEM mounted adjacent to the compressor. There are two basic types of gas seal systems - differential pressure (D P) control and flow control.

**D.P systems** -control the supply of seal gas to the seal by regulating the seal gas pressure to a predetermined value (typically 10 PSI) above a reference (sealing) pressure. This is accomplished through the use of a differential pressure control valve.
**Flow control systems** control the supply of seal gas to the seal by regulating the seal gas flow through an orifice upstream of the seal. This can be accomplished with a simple needle valve, or through the use of a differential pressure control valve monitoring pressures on either side of the orifice.
Since D P systems basically control the flow of seal gas through a labyrinth seal, this can sometimes result in high seal gas flows through the inner seal labyrinth. Variations in the inner seal labyrinth clearance can result in high variations of seal gas flow. The majority of the seal gas flow across the inner seal labyrinth and back into the compressor, and very little flow is actually required for the gas seal. This "recycled" flow is inefficient and uses more energy. This situation becomes more critical in high pressure applications due to the higher mass flows of gas involved. Since the flow control systems control the flow of seal gas through an orifice, the flow rate is constant and does not vary with labyrinth clearance. Flow controls systems can be applied when reduced seals gas flow are desirable.


PDC
PDI
SEAL GAS
REFERENCE
SEPARATION
GAS SUPPLY
SEAL GAS
SUPPLY
PT
PERM. TO START OIL PUMPS
LOW PRESSURE ALARM
DUPLEX FILTERS
GAS BALANCE
SECONDARY VENT
PRIMARY
VENT
PRIMARY
VENT
SECONDARY VENT

**Differential Pressure Control System**


PDC
PDI
SEAL GAS
REFERENCE
SEPARATION
GAS SUPPLY
SEAL GAS
SUPPLY
PT
PERM. TO START OIL PUMPS
LOW PRESSURE ALARM
DUPLEX FILTERS
GAS BALANCE
SECONDARY VENT
PRIMARY
VENT
PRIMARY
VENT
SECONDARY VENT

**FLOW CONTROL SYSTEM**

## GAS SEAL Contamination

The running gap between the primary and mating gas seal rings is typically around 3 to 4 microns, about 1/20th the diameter of a human hair. Ingress of foreign material (solid or liquid) into this very narrow seal running gap can cause degradation of seal performance (excessive gas leakage to the vent) and eventual failure of the seal.
Foreign material within the running gap of the seal results in increased shearing forces between the primary and mating rings. The seal components then overheat, leading to some form of mechanical seal failure such as O-ring deterioration, mating ring cracking etc.).
There are three primary sources if gas seal contamination:
☐ Process gas (from the inboard or high-pressure side of the seal)
☐ bearing lubrication oil (from the outboard or low–pressure side of the seal)
☐ Seal gas supply itself (injected into the seal)

## Contamination from Process Gas

Contamination from process gas can occur when there is insufficient sealing gas pressure to overcome the reference pressure, allowing gas to come into direct contact with the seal ring face. Contaminants existing within the process gas can then damage the seal.

## Contamination from Bearing Lubrication Oil

A barrier seal is required on the outboard side of the dry gas seal, between the gas seal and the compressor bearing housing area. This seal is typically buffered with air or nitrogen. The primary function of the barrier seal is to prohibit the flow of bearing lubrication oil or oil mist into the gas seal.

Contamination of the dry gas seal from lube oil can occur when the barrier seal fails o function as intended.

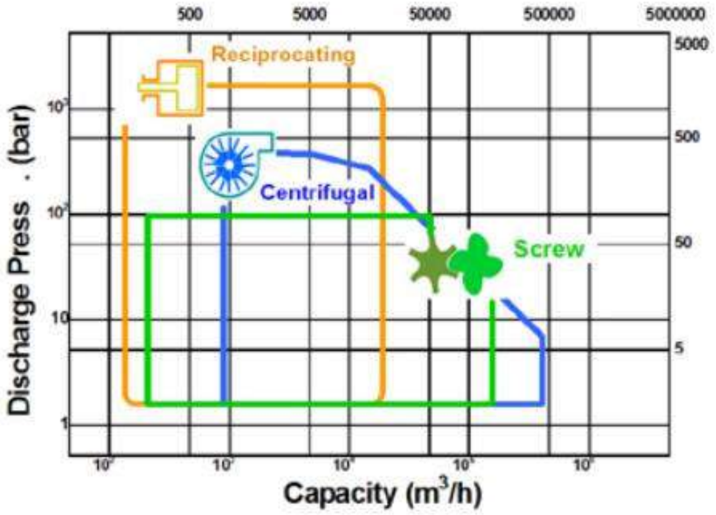
**Contamination from Seal Gas Supply**

Contamination from the seal gas supply occurs when the sealing gas is not properly treated upstream of the dry gas seal. Gas seal manufacturers have strict requirements for seal gas quality. Typically, the sealing gas must be dry and filtered of particles 3 micron (absolute) and larger. Filters are normally provided in the gas seal system to address this requirement. While typical systems are supplied with coalescing–type filters, such devices may be inadequate depending on the source of seal gas supply.

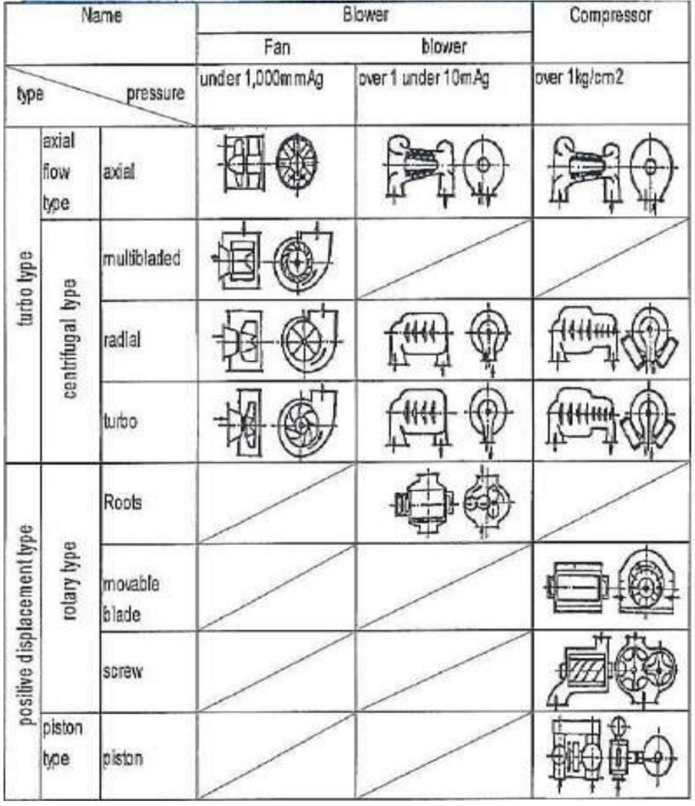
**Measures to Improve Gas Seal Reliability**

All three types of contamination described previously are influenced by the approach taken in the design of the gas seal environment, the availability of the seal gas sources of supply to cover all operating conditions, and the operation and maintenance of the compressor or gas seal system. There are various design, operation and maintenance techniques that can be applied to lessen gas seal contamination and increase gas seal reliability/ availability.

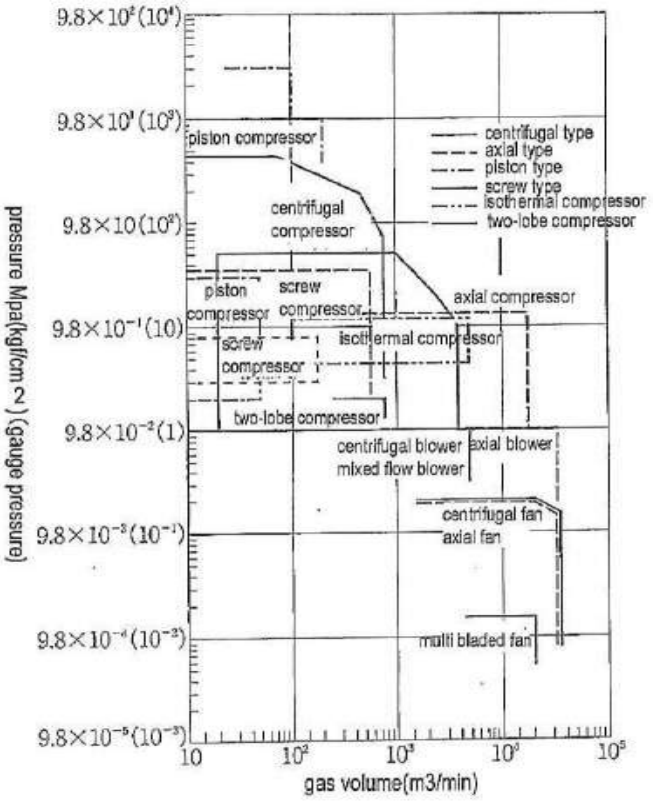
- **Difference between Fan, Blower & Compressor**
  - ✓ **Fans**: Machines that can develop pressures up to 0.07 bar
  - ✓ **Blowers:** Machines that can develop pressures up to **2.5** bar
  - ✓ **Compressors:** Machines that can develop pressures **more than 2.5** bar



## APPLICATION RANGE OF FAN, BLOWER AND COMPRESSOR



| Name | | | Blower | | Compressor |
|---|---|---|---|---|---|
| | | | Fan | blower | |
| type / pressure | | | under 1,000mmAg | over 1 under 10mAg | over 1kg/cm2 |
| turbo type | axial flow type | axial | | | |
| | centrifugal type | multibladed | | | |
| | | radial | | | |
| | | turbo | | | |
| positive displacement type | rotary type | Roots | | | |
| | | movable blade | | | |
| | | screw | | | |
| | piston type | piston | | | |



- **Circuits of compressor**
  1) Air / process circuit 2 ) Lube Oil circuit
  3) Cooling circuit 4) Loading / unloading circuit.
- **Parameters to be checked of compressors.**
  1) Suction / discharge pressure – each stage
  2) Suction / discharge temperature – each stage
  3) Intercooler / stage pressure / temp.
  4) Lube oil pressure / temp.
  5) Cooling water pressure / temp – inlet / outlet

6) Motor amp. – load/unload condition
7) Vibration reading
8) Sealing / packing condition

- **why loading / unloading circuit require**
  Purpose of loading / unloading circuit is to unload the compressor when more pressure is being generated than being consumed.
- **what are the common method of controlling compressor**
  1)Clearance method 2 ) Blow off control 3 ) Throttle control

- **What is the difference between pressure developed by a pump and pressure developed by a compressor**
  1. A Pump always maintains a developed head (Discharge Pressure - Suction Pressure.)
  2. Compressor always maintains the pressure ratio (Discharge Pressure/Suction Pressure.)

- **What is the balance piston used for a centrifugal compressor?** Due to the pressure rise developed through the impeller, a pressure difference exists across the hubs and covers such that the impellers have a net thrust in the direction of the compressor inlet. The balance piston counteracts that by being located behind the last impeller. This is accomplished by subjecting the outboard side of the balance piston to a low pressure from the inlet side of the compressor thereby creating a pressure differential opposite to the direction of the impellers. This pressure is achieved by connecting the area behind the piston to the inlet using a line. The impeller thrust not balanced by the balance piston is absorbed by the thrust bearings.

- **Where the head does gets developed in a centrifugal compressor?** Head is developed in the compressors partially in the impeller itself and partly in the diffuser / volute.
- **What sorts of bearings are used for high speed compressors?** Hydrodynamic type bearing like sleeve or tilting pad bearings are generally used for compressors.
- **In what services barrel compressors are used?** Barrel compressors are radial split compressors. These are used for very high pressures. These machines are used in very light and highly flammable gases.
- **How the centrifugal compressors are sealed?** Dry gas seal or wet-seals are used at compressor ends to prevent leakage of process gases to the atmosphere.
- **What types of seals are used for air compressor?** Labyrinth seals or carbon bushings are generally used for air compressors.
- **What types of seals are more reliable in hazardous services?** Non-contact type seals (Dry gas seals) are more reliable than wet seals or oil ring type of seals.
- **What should be the seal configurations in hydrocarbon services?** Generally tandem seals which deploys aback up seal are used. double seals are also used.
- **How does identify seal leakage?** Seal health can be monitored by seal gas flow at inlet and outlet and also the outlet pressures.
- **What are compressor protections?** Alarm and trips are given on certain parameters like vibrations, axial position, lube-oil pressure, bearing temperatures, etc. Operation of machine beyond permitted values can cause serious damages, hence need to be avoided.
- **Are liquids in the process detrimental to compressors?** Substantial amounts of liquid can cause valves, piston rings –guide rings, packing, bearing and seal failures.
- **What is turndown in compressor?** Minimum capacity at which compressor can be operated is called turndown.
- **Reciprocating compressor can be control / regulate by…**
  1) Suction unloader 2) Bypass (discharge to suction) , 3) Clearance pocket
  4) Variable speed

- **What is application of piston ring and rider ring in reciprocating compressor?**

The basic difference between lubricated and non lubricated compressor – the piston works against pressure and should sliding seal so that it can compress the gas without leakage so in lubricated cylinder piston would be plug piston with very close fit to cylinder bore but because of temperature and pressure or other reasons piston rings are used for sealing which is thin metallic split ring fitted on piston groove , this ring made with spring or tension which tends to push out against the cylinder wall and make close / tight sliding fit , piston ring do not support piston its float in ring grooves of the piston , the piston is supported by thin oil film to the cylinder wall .
In non lube / oil free compressor ,piston supported by rider ring which is also refer as wear , bull or rider ring is low friction material like carbon or Teflon

- **Why Reciprocating Compressor used?**
  Reciprocating compressors are used when intermittent duty cycle is required. They are offered as single or multi-stage. Reciprocating Compressors typically offer a lower installation cost, low noise level, and a relatively low maintenance cost.

- **What are the basic components of a reciprocating compressor valve?**

Most valves have five basic components:

- Seat
- Guard (guard, stop plate, buffer, plate, etc.)
- Sealing element (valve plate or valve ring, channel, poppet, feather strip, ball, etc.)
- Damping element (coil springs, cushion plates, spring plates, damping plates, etc.)
- Assembly element (bolts, nuts, retainer ring, etc.)

- **Are there different kinds of reciprocating compressor valves?**

There are several different kinds of compressor valves: plate valves, ring valves, channel valves, feather valves, poppet valves..etc. Each design has specific criteria with regard to the sealing element and all the other components are designed accordingly.

- **What does a reciprocating compressor valve do?**

A compressor valve regulates the flow of air / gas in a compressor cylinder. There is at least one suction valve and one discharge valve for every compression chamber. Each valve opens and closes with every cycle of the piston.

There are two objectives...efficiency and durability. The aerodynamic flow efficiency depends greatly on the restrictions in the valve. The gas must pass through the seat area around the fully opened valve plate (free lift area) and escape through the guard. On most valves, the minimum flow area is the free lift area and this is the area most frequently compared in valve analysis. It takes into account that the valve is fully open.

**A general rule**: the higher the valve lift area the more efficient the valve.

A more meaningful comparison is the free lift area of two valves at equal lift. A higher valve lift may mean higher area, but also means less durability.

**Lower lift valves are typically more durable.**

The flow resistance is further influenced by other factors such as surface friction, directional changes in the gas flow, turbulence within the valve, spring load, etc. Seats with cast slots are not as good as milled slots tapered and properly deburred. Slotted seats, in general, are better than seats with drilled holes, particularly if the seats are made with a few drilled holes of large diameter. Hanging or open guards are often better than safety guards with respect to aerodynamic flow.

- **Can a valve comparison be made without running an actual test and total instrumentation of the compression cylinder?**

There are two phases in analyzing valves:

1) Comparing design criteria and data without actual tests. This can go as far as computer simulated performance diagrams, based on experimental data gathered in actual tests.

2) Installation of valves in the cylinder and complete analysis of the results combined with a subsequent life test.

- **What does a valve dynamic mean?**

A compressor valve opens and closes with every compression cycle. The timing and pattern of these events are referred to as valve dynamics. It is important that the valve opens and closes at the right time and does not flutter. Compressor valve dynamics influence valve life and compression efficiency. Springing and the mass of the moving components affect valve dynamics. For proper performance, valves are designed for specific operating windows.

- **Valve efficiency. How about durability?**

It is difficult to predict how long a valve will work. There are, however, certain criteria that will increase the probability of lasting valve performance:

- Lower rpm
- Lower valve lift
- Sealing elements (plates, rings) with simple shape tend to have a higher fatigue resistance than parts of more intricate shape. Good mechanical cushioning and damping elements tend to minimize impact forces and definitely increase life. Air cushioned valves are not a mechanically controlled damping system. They depend solely on maintaining correct production tolerances, both in manufacture and after repair. Most sealing elements are made from glass-fiber or carbon fiber filled composite materials, such as nylon and PEEK. Steel plates and ring are less common. These new materials have proved very effective in valve applications. Composites work better in difficult services enduring contaminants

- **If a valve breaks prematurely, is it always due to improper design or inadequate production?**

No, a compressor valve is an integral part of a larger piece of equipment. Often problems show up in the valves that are caused by outside factors. Carryover of foreign material , liquid can cause valve failure. Pulsations in the system can sometimes cause valve flutter. Changes in operational use from original design conditions are often the cause of frequent breakage. Improper valve repair and maintenance also cause short life.

**What is CFM?**

The CFM (Cubic Feet per Minute) refers to a volume of air/gas produced by the compressor at a given pressure or PSI (Pound per Square Inch)

**What is Duty Cycle?**

A compressor's duty cycle determines the percentage of run time in a full cycle. A full cycle is determined by adding the compressor run time to its rest time.

- **What is pressure in crankcase of reciprocating compressor?**

...It will be whatever your suction pressure is

- **What is bumping in reciprocating compressor?**

Bumping clearance is the clearance between piston and head, piston and crank end side

- **Difference between lubricated & non lubricated reciprocating compressors**

Lubricated Recipe comp. means lubricant is fed between bearings shaft ,cylinder & pistons wherever lubrication is required , non lubricated compressors means lubrication is done in shaft & bearings but cylinder & piston no lubrication because air /gas supply is required should be oil free & moisture free special purpose around cylinders they provide water jacket to remove heat during cylinder & piston friction plus metal used in cylinders & piston is of special grade that does not allow to get jamming of pistons air from non lubricating comp. is required for pneumatically operated machines & instruments where oil free moisture free dry air is required .

- **What is hermetic compressor?**

A fully welded or serviceable in **hermetically sealed compressor**, the compressor and the motor are enclosed in the welded steel casing and the two are connected by a common shaft. This makes the whole compressor and the motor a single compact and portable unit that can be handled easily. The hermetically sealed compressor is very different from the traditional open type of compressors in which the compressor and the motor are different entities and the compressor is connected to the motor by coupling or belt.

- **What is capacity control with reciprocating compressor?**

Capacity control is the process by which the flow of the discharged gas from the compressor is controlled. This can be accomplished by several methods.

1. Controlling the speed of the compressor.
2. Controlling the clearance of the compressor.
3. Throttling the suction valve.
4. Suction valve unloader.

- **what is the difference between axial flow compressor and centrifugal compressor**

The centrifugal flow compressor has a single or two stage units using an impeller to accelerate the air and a diffuser to produce the required pressure rise. The axial flow compressor is a multi-stage unit using alternate rows of rotating (rotor) blades and stationary (stator) vanes, to accelerate and diffuse the air until the required pressure rise is reached. Particularly on small engines, an axial compressor is used to boost the inlet pressure to the centrifugal.

The centrifugal compressor is more rugged than the axial and is also easier to develop and manufacture. But the axial compressor consumes more air than a centrifugal compressor even with the same frontal area. Axial also can be designed to attain much higher pressure ratios.

Air flow is an important factor because it determines the amount of thrust. Axial compressor engine gives more thrust for the same frontal area of a centrifugal. Also, the axial has the ability to increase its pressure ratio by adding extra stages. But centrifugals are still used in smaller engines which are simple and rugged

**What are the benefits of screw compressors over reciprocating compressors?**

Screw compressors can handle dirt and fouling services whereas recip compressors cannot.

**What are the advantages of wet screw compressors over dry screw?**

Wet screw compressors offer higher pressure ratios in comparison with dry screws.

**What are the main application areas of screw compressors?**

Screw compressors are widely used in air, refrigeration and process services.

**How much reliable screw machines are?**

Being rotary in motion, these machines have fairly very high reliability in comparison to reciprocating compressors.

**How metal to metal contact is avoided in dry screw compressors?**

Timing gears are used to synchronize the motion of two rotors; which prevents contact of two screws.

**How wet screw compressor s different than dry screw compressor?**

Oil is injected in the process gas for the complete compression process in wet screw compressors.

**What types of bearings are employed in screw compressors?**

Smaller machines may be fitted with antifriction radial and thrust bearings. Larger machines have shell type heavy duty journal bearings combined with tilting pad type thrust bearings.

**How are bearings lubricated in large screw machines?**

Bearings are lubricated with the use of pressure lubrication system.

## HEAT EXCHANGERS

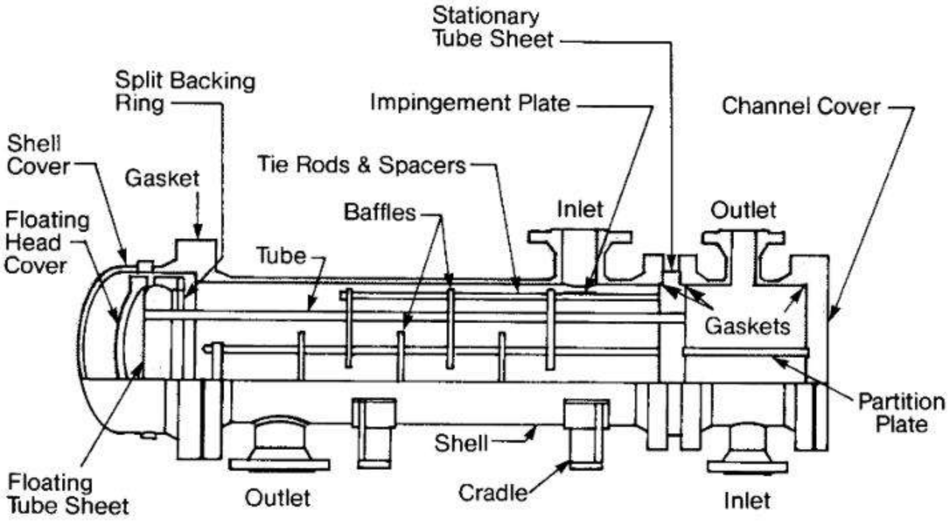
A heat exchanger is equipment used for exchange or transfer of heat between different streams. Based on the type of heat exchange a heat exchanger can be called as…….

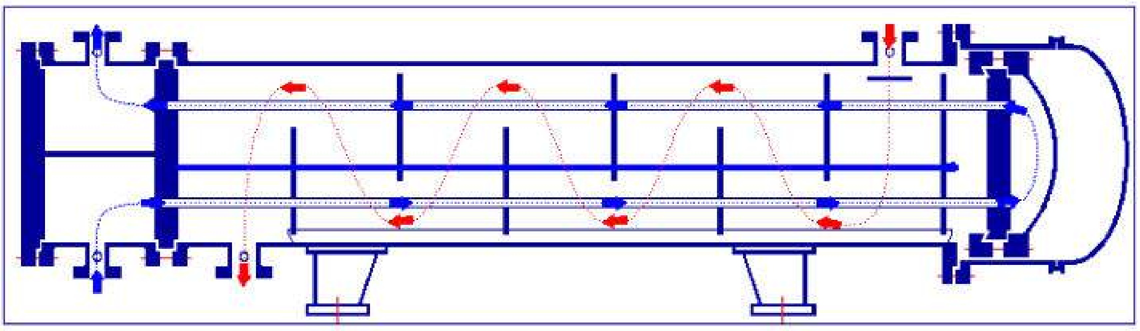
1. Heater
2. Cooler
3. Condenser
4. Re-boiler
5. Evaporator

**The industrial heat exchanger are varies depending upon**

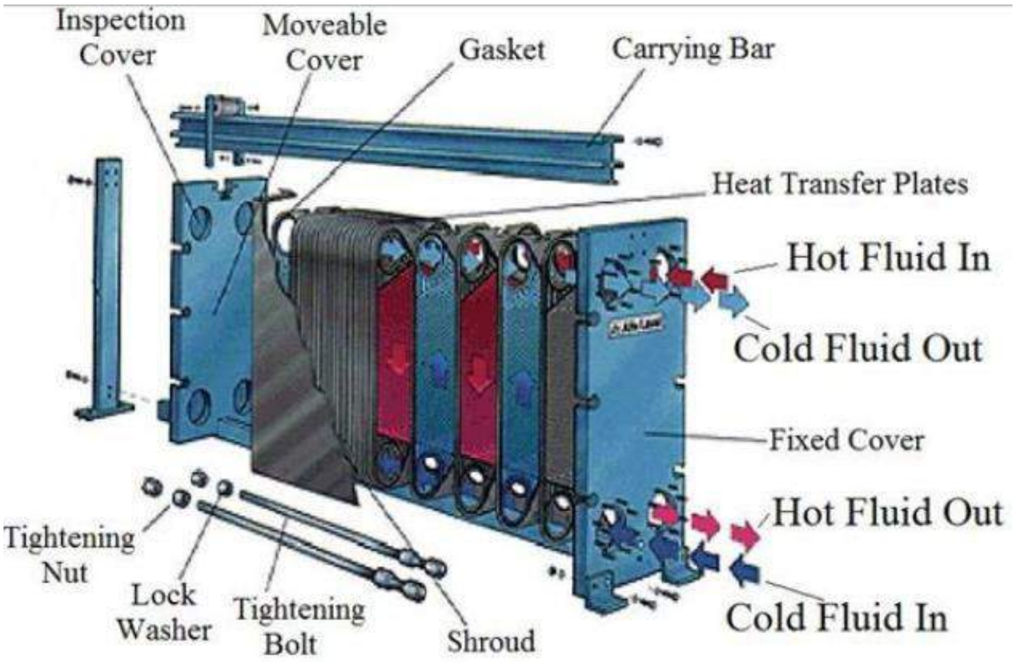
1. Transfer process.
2. Number of fluids
3. Compactness.
4. Constriction.
5. Flow arrangement.
6. Type of heat transfer.

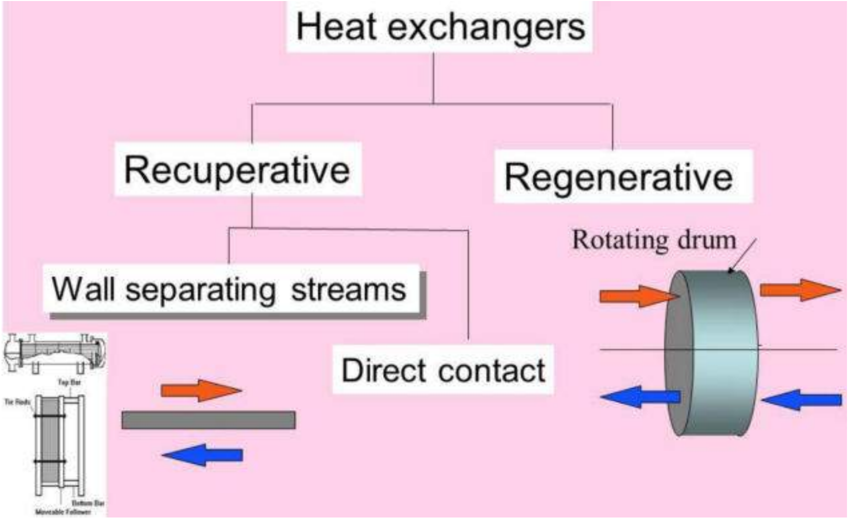
### SHELL AND TUBE TYPE EXCHANGER


Stationary Tube Sheet
Split Backing Ring
Impingement Plate
Channel Cover
Shell Cover
Gasket
Tie Rods & Spacers
Floating Head Cover
Baffles
Inlet
Outlet
Tube
Gaskets
Partition Plate
Shell
Floating Tube Sheet
Outlet
Cradle
Inlet



### PLATE TYPE EXCHANGER


Inspection Cover
Moveable Cover
Gasket
Carrying Bar
Heat Transfer Plates
Hot Fluid In
Cold Fluid Out
Fixed Cover
Hot Fluid Out
Cold Fluid In
Tightening Nut
Lock Washer
Tightening Bolt
Shroud

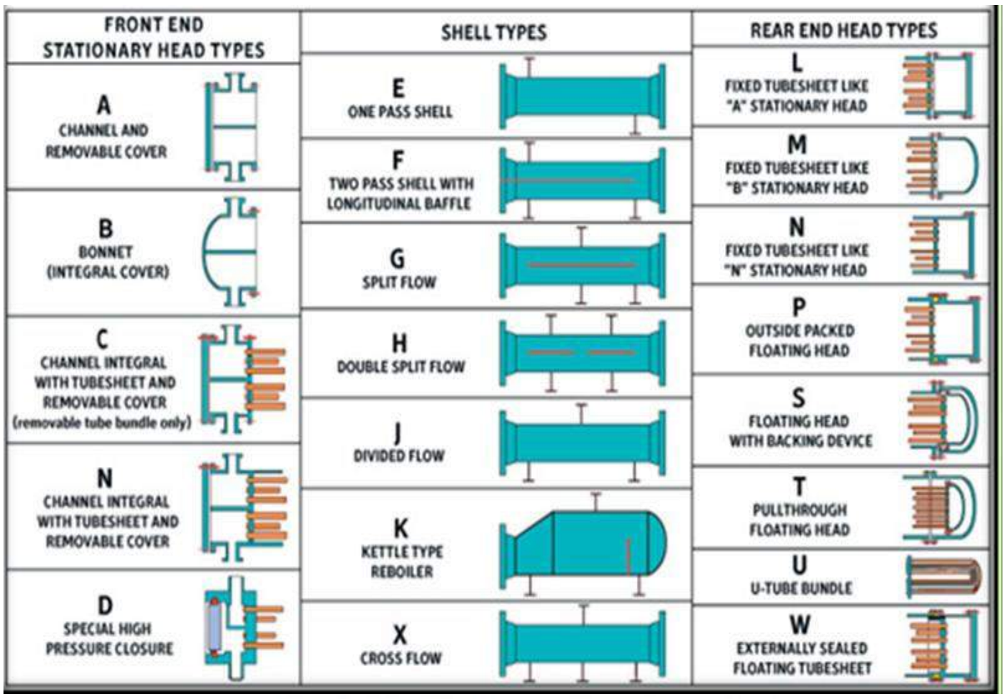


**Heaters are** primarily used to heat fluids by using steam/hot fluids generally as source of heat.

**Coolers are** employed to cool process or non process streams, normally, water being used as cooling medium.

**Condensers are** coolers whose primary function is to remove latent heat and not sensible heat from the streams. Condensers cool at constant temperatures. They only change the phase

**Reboilers are** the heat exchangers, which are used to supply heat requirements of as distillation process as latent heat.



**FRONT END STATIONARY HEAD TYPES**

- A CHANNEL AND REMOVABLE COVER
- B BONNET (INTEGRAL COVER)
- C CHANNEL INTEGRAL WITH TUBESHEET AND REMOVABLE COVER (removable tube bundle only)
- N CHANNEL INTEGRAL WITH TUBESHEET AND REMOVABLE COVER
- D SPECIAL HIGH PRESSURE CLOSURE

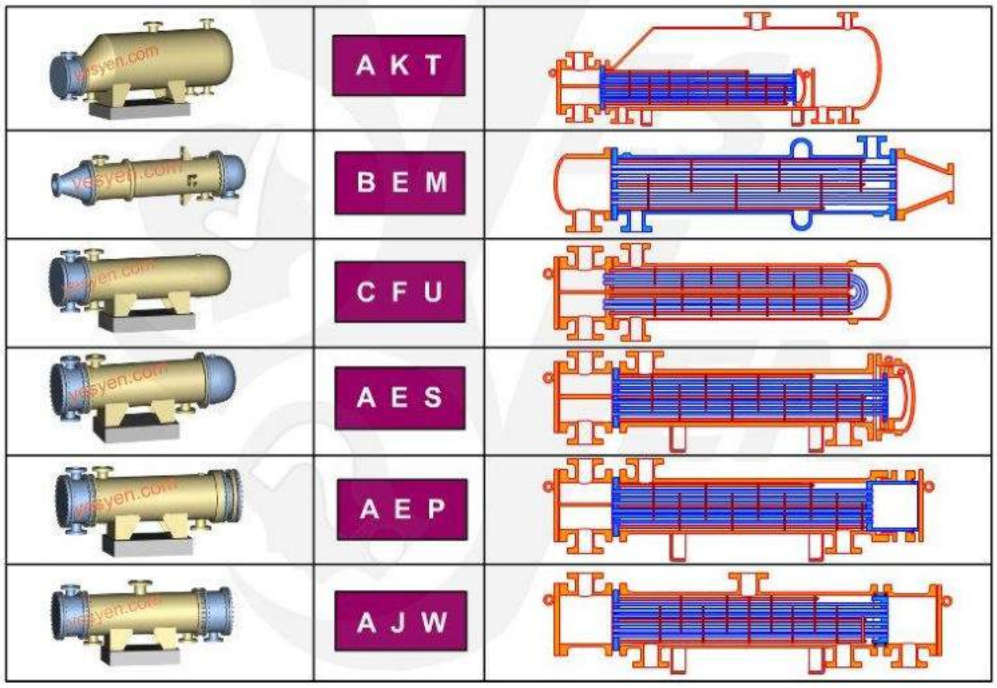
**SHELL TYPES**

- E ONE PASS SHELL
- F TWO PASS SHELL WITH LONGITUDINAL BAFFLE
- G SPLIT FLOW
- H DOUBLE SPLIT FLOW
- J DIVIDED FLOW
- K KETTLE TYPE REBOILER
- X CROSS FLOW

**REAR END HEAD TYPES**

- L FIXED TUBESHEET LIKE "A" STATIONARY HEAD
- M FIXED TUBESHEET LIKE "B" STATIONARY HEAD
- N FIXED TUBESHEET LIKE "N" STATIONARY HEAD
- P OUTSIDE PACKED FLOATING HEAD
- S FLOATING HEAD WITH BACKING DEVICE
- T PULLTHROUGH FLOATING HEAD
- U U-TUBE BUNDLE
- W EXTERNALLY SEALED FLOATING TUBESHEET

POPULAR SHELL & TUBE HEAT EXCHANGER TYPES



- A K T
- B E M
- C F U
- A E S
- A E P
- A J W

**Construction of Heat Exchangers –**

**Types -**Most commonly used type of heat exchanger is **Shell & Tube Heat Exchange**. This type of heat exchanger consists of tubes in parallel arranged in a bundle. This tube bundle is then enclosed in a single shell. While one fluid steam flows inside the tubes, the other flows through the shell.

Different types of shell & tube heat exchangers are employed in process operation.

They are:

**Stationary or fixed tube sheet heat exchangers**

In this type tubes are expanded into two tube sheets at the ends of the tubes and these tube sheets are then fixed to the shell.

**Drawbacks:** Sudden cooling or sudden heating in this type of heat exchanger may lead to bending or collapsing of tubes as tube sheets are fixed or may pull the tubes loose from the tube sheets. Since tubes are thin walled compared to shell, which is normally made up of cast iron construction, shell heating or cooling is much slower compared to that of tubes. Due to this thermal strains may develop in shell causing its failure. Inside of the tubes cleaning by wire brush or mechanical means is easy, where as tubes outside cleaning is not so easy as tube bundle cannot be pulled out. Therefore these heat exchangers are not suitable if shell side process streams are dirty

**Floating head heat exchangers**

Here one tube sheet floats in shell or the shell. It may not be possible to pull out tube bundle from the shell. But back cover can be opened to expose tube ends. This type of heat exchanger is particularly suited for operations where temperature variations are too large. Because, since one tube sheet is free and floating, expansion of tubes cannot cause breaking or bending of tubes. Also in case, if we can pull out tube bundle, outside of the tube cleaning also becomes easy.

**Drawbacks:** Internal leakage of floating head cover cannot be easily detected.

**U-tube bundle heat exchangers**

This type of exchanger consists of only one tube sheet and all the tube are bent in U-shape. These can withstand higher temperature variations due to U-bending of the tubes. Inner side and outer side of tubes can be easily cleaned by pulling out the tube bundle.

**Drawbacks:** Danger of mechanical damage or rupture of tubes at U-bend. High velocity of tube side fluid or presence of suspended particles may cause tube damage.

**Plate & Frame heat exchangers**

This is another type of heat exchanger, which is made up of metallic thin plates separated by gaskets. They are very compact and easy to clean.

**Drawbacks:** Cannot be used for fluids of excessive pressure difference ,Due to use of a lot of gasket material, leakage probability increases

**Double pipe heat exchanger**

**Multipass Heat Exchangers**

In the simplest type of shell & tube (fixed tube sheet) heat exchanger the fluid on tube side, enters the tube from one end, flows or passes only once through the tubes and comes out from the other end. This called one pass on tube side.

Similarly, shell side fluid enters the shell from one end, passes only once through the shell and comes out from the other end of the shell. This is called one pass on shell side.

The flow velocity of the fluid and hence the heat transfer rate can be increased by having more than one pass (or multi passes) on both shell and tube side. Baffles are used for this purpose.

A 1.1-heat exchanger means one pass on shell side and one pass on tube side.

A 1.2-heat exchanger means one pass on shell side and two passes on tube side.

## Re-Boilers

Normally in Re-boilers the heat transfer takes place from the condensing media (for example steam) on shell side to a fluid on tube side. The fluid on tube side is circulated in three ways and accordingly the Re-boilers are classified in following categories

### Types of Re-Boilers

### 1. Forced circulation Type

If a pump is used to push or force the liquid through the tubes of re-boiler then it is called forced circulation Re-boiler

### 2. Natural Circulation Type (Thermosyphon)

Whenever a fluid is heated its volume increases and hence its density decreases. In a heat exchange, when a fluid inside the tube is in contact with the heated surface of the tube, it tends to rise inside the tube due to decrease in its density and gets replaced by a colder portion of the fluid having higher density. Thus a motion of fluid molecules sets in. Such a fluid motion or circulation caused by density difference arising out of temperature gradient inside the fluid is known as natural circulation or Thermo-siphoning

### 3. Falling Film Type

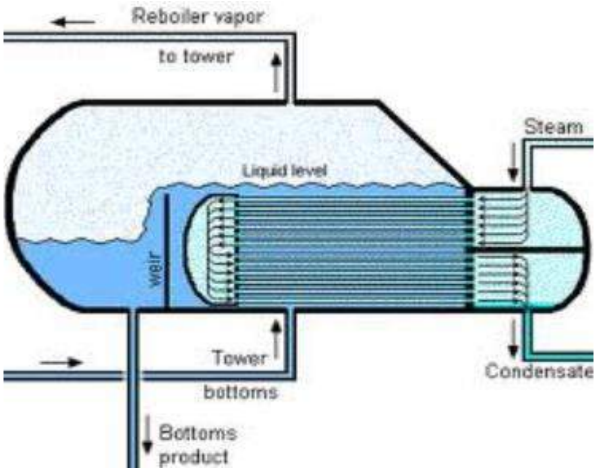
A Falling film type re boiler is usually a 1-1 fixed tube sheet heat exchanger, designed to operate vertically. Here the tube side fluid (normally a process) enters from top at such a rate that tubes do not flow full of liquid and thereby flows down by gravity touching the tubes wall and have minimum residence with hot surface.

These types of re-boilers are used when the process fluids are heat sensitive. The ones that may undergo thermal degradation, which is the reason these are usually used for Glycol Distillation process.

- **What is a weir in Heat Exchanger?**

Weir is basically a projected plate, which will overflow to other side, maintaining a level upstream,

**Purpose**: Weir plate ensures that the tube bundle is always remaining submerged in the pool of liquid and there is no dry surface at all during heat transfer process



- **Why to keep open the bypass of weir?**

To avoid salt build up, continuous flow will ensure to have a blow down and hence salt levels will never build up.

- **What is fouling in heat exchangers?**

Fouling is basically a deposit of dirt on the surface of tubes of a heat exchanger. This dirt can be salts, mud, soil etc. Due to this deposit, the heat transfer area of the heat exchanger is reduced and finally the exchanger cannot deliver the required duty.

**What causes fouling?**

Basically there are two contributors for Fouling

1. Low Velocity
2. High temperature

Both these factors speed up fouling rate.

**What is the purpose of cleaning exchanger?**

The purpose of cleaning an exchanger is to remove the deposit and bring back the surface area to heat transfer.

**FOULING FACTORS**

In the actual service of heat exchangers, the heat transfer surface does not remain clean with time. Scale, dirt and other solids such as salt, carbon, algae etc. deposit on one or both sides of the tubes. Such deposits act as resistance to heat transfer and reduce heat transfer rate. Chemical inhibitors are often added to avoid or reduce these fouling problems. Water velocity above 1M/sec. is generally used to reduce fouling. A factor called as fouling factor is used in overall heat transfer coefficient to account for fouling in the heat exchangers.

**Heat Exchanger Types and Selection**

- Application (i.e. sensible vapor or liquid, condensing or boiling)
- Operating pressures & temperatures (including startup, shutdown, normal & process upset conditions)
- Fouling characteristics of the fluids(i.e. tendency to foul due to temperature, suspended solids ...)
- Available utilities (cooling tower water, chilled water, steam, hot oil...)
- Temperature driving force (i.e. temperature of approach or cross and available )
- Plot plan & layout constraints
- Accessibility for cleaning and maintenance
- Considerations for future expansions
- Mechanical considerations such as: 1) material of construction; 2) thermal stresses (during startup, shutdown; process upset and clean out conditions); 3) impingement protection
- purchase cost
- installation cost
- Operating cost (pumping, fan…)
- maintenance cost

## Shell & tube Exchanger cleaning Work

**1 . ISOLATION & preparation:**

- Isolation: De-pressurize pipelines and Isolate/close all valves of those pipelines connected with exchanger.
- Empty the pipeline from the product and push it to the stripping line.
- Install the spades on upstream & downstream to blind the lines.
- Installation scaffolding and removal of insulation , arrange lightning
- Check for exchanger gasket (dimension, physical, property ...etc..)
- Review data sheet & drawing for test pressure (shell side & tube side), gasket, weight. Etc.

**2 . INSPECTION** :

- **External Inspection** – The inspection is performed on the external to determine if leaks, mechanical or structural damage is present. Inspection is performed at least every five (5) years or at the quarter corrosion-rate of the shell, whichever is less.
- **Internal Inspection** - The internal inspection involves a complete visual inspection, by U.T. or other NDT techniques, on all structures / parts , tube wall thickness , tube physical check ,baffles , support plates, gasket contact surface , nozzles..etc

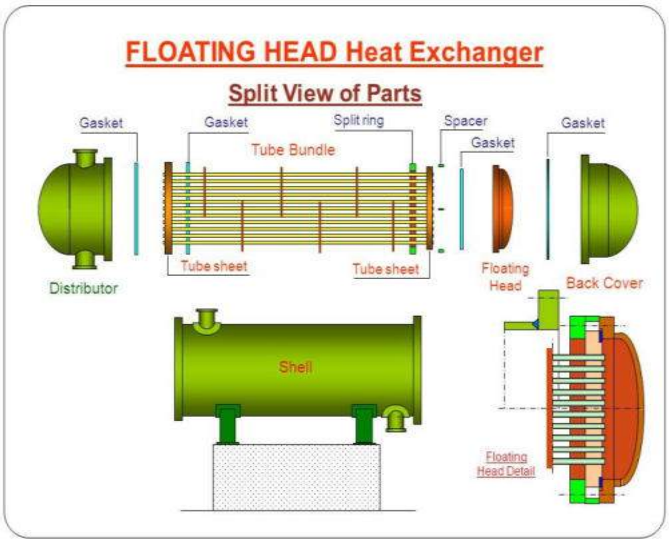
### 3. Cleaning :

- Open CH , floating head cover ..etc..
- tube cleaning by means of hydro jetting machine ( 10000 – 15000 psi )using flexible lancing & external tube cleaning for bundle (7000 -10000 psi) .
- To remove tube bundle , need bundle puller , crane , fork lift , chain block , d shackle , sling ..etc..
- Inspect tube & shell for any damage , leak , crack ..etc..
- Hydro test tube side & shell side after cleaning and box up
- If tube leak , plug properly and do hydro test again . Exchangers are designed 1.5 times against requirement so normally 8 to 10% of tube can be plug of total tube for better operation.

**4 . Box up** : after hydro test and physical inspection , box up exchanger with proper torqueing value (stud / bolt – refer torqueing chart for tightening value )

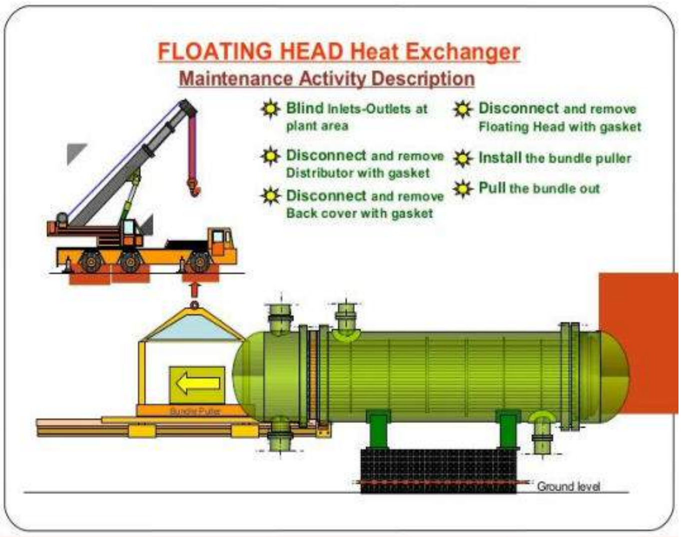
**Reference** : API 660

**Shell & tube exchanger cross section drawing / cleaning activity:**


FLOATING HEAD Heat Exchanger

Split View of Parts

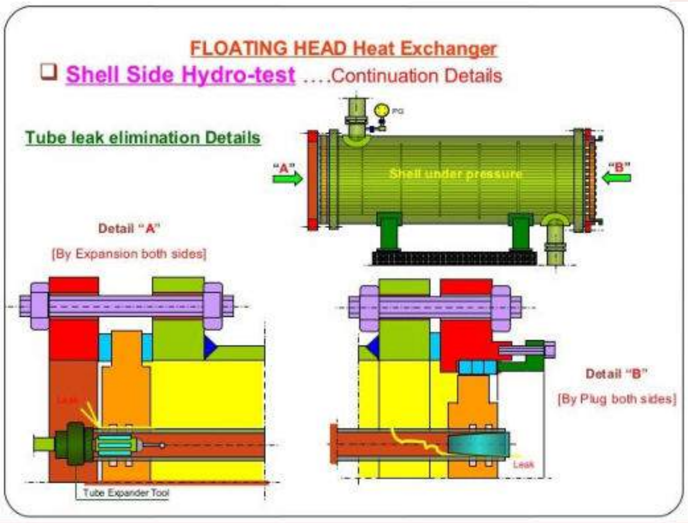
Gasket
Gasket
Split ring
Spacer
Gasket
Gasket
Tube Bundle
Tube sheet
Tube sheet
Distributor
Floating Head
Back Cover
Shell
Floating Head Detail


FLOATING HEAD Heat Exchanger

Maintenance Activity Description

- Blind Inlets-Outlets at plant area
- Disconnect and remove Distributor with gasket
- Disconnect and remove Back cover with gasket
- Disconnect and remove Floating Head with gasket
- Install the bundle puller
- Pull the bundle out

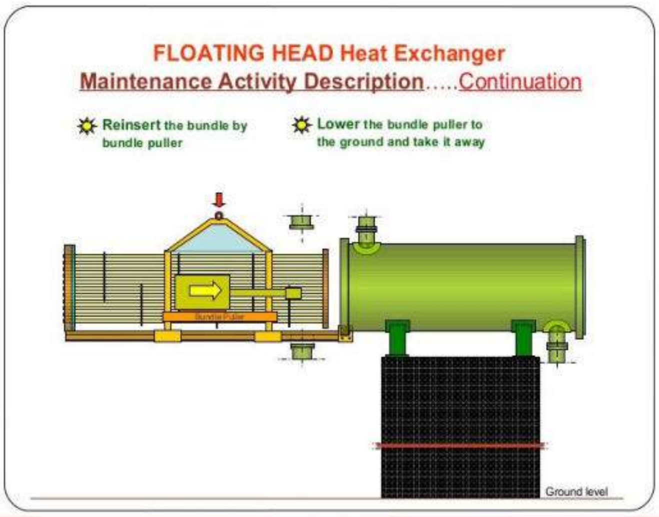
Bundle Puller
Ground level


FLOATING HEAD Heat Exchanger

❑ Shell Side Hydro-test ….Continuation Details

Tube leak elimination Details

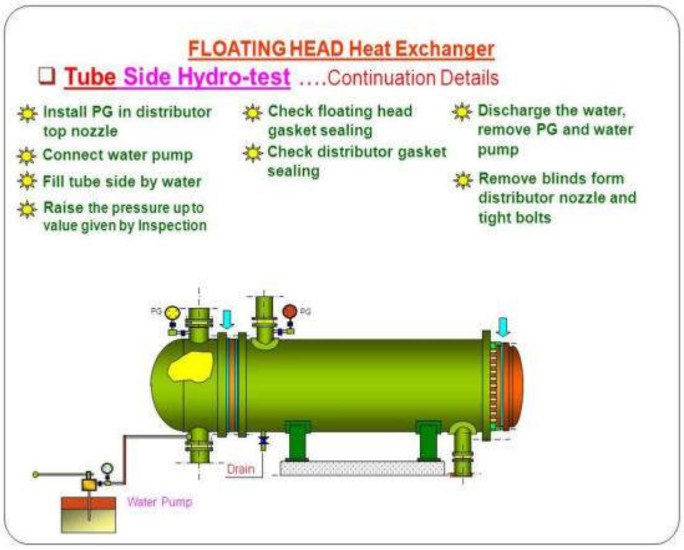
PG
"A"
"B"
Shell under pressure
Detail "A"
[By Expansion both sides]
Leak
Tube Expander Tool
Detail "B"
[By Plug both sides]
Leak


FLOATING HEAD Heat Exchanger

Maintenance Activity Description…..Continuation

- Reinsert the bundle by bundle puller
- Lower the bundle puller to the ground and take it away

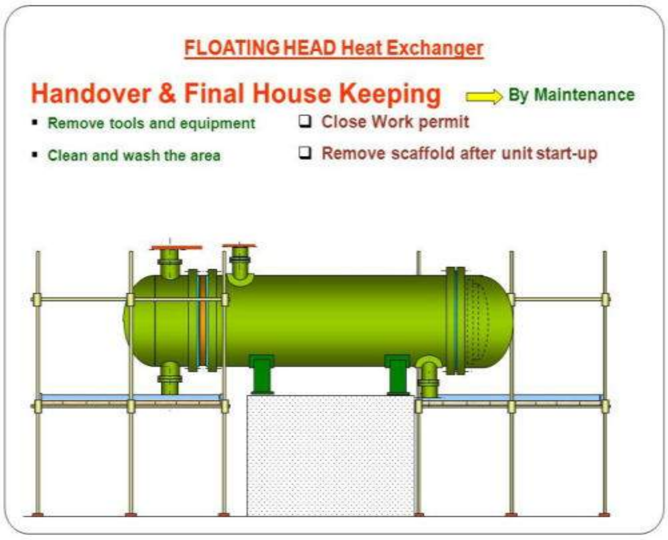
Bundle Puller
Ground level


FLOATING HEAD Heat Exchanger

❑ Tube Side Hydro-test ….Continuation Details

- Install PG in distributor top nozzle
- Connect water pump
- Fill tube side by water
- Raise the pressure up to value given by Inspection
- Check floating head gasket sealing
- Check distributor gasket sealing
- Discharge the water, remove PG and water pump
- Remove blinds form distributor nozzle and tight bolts

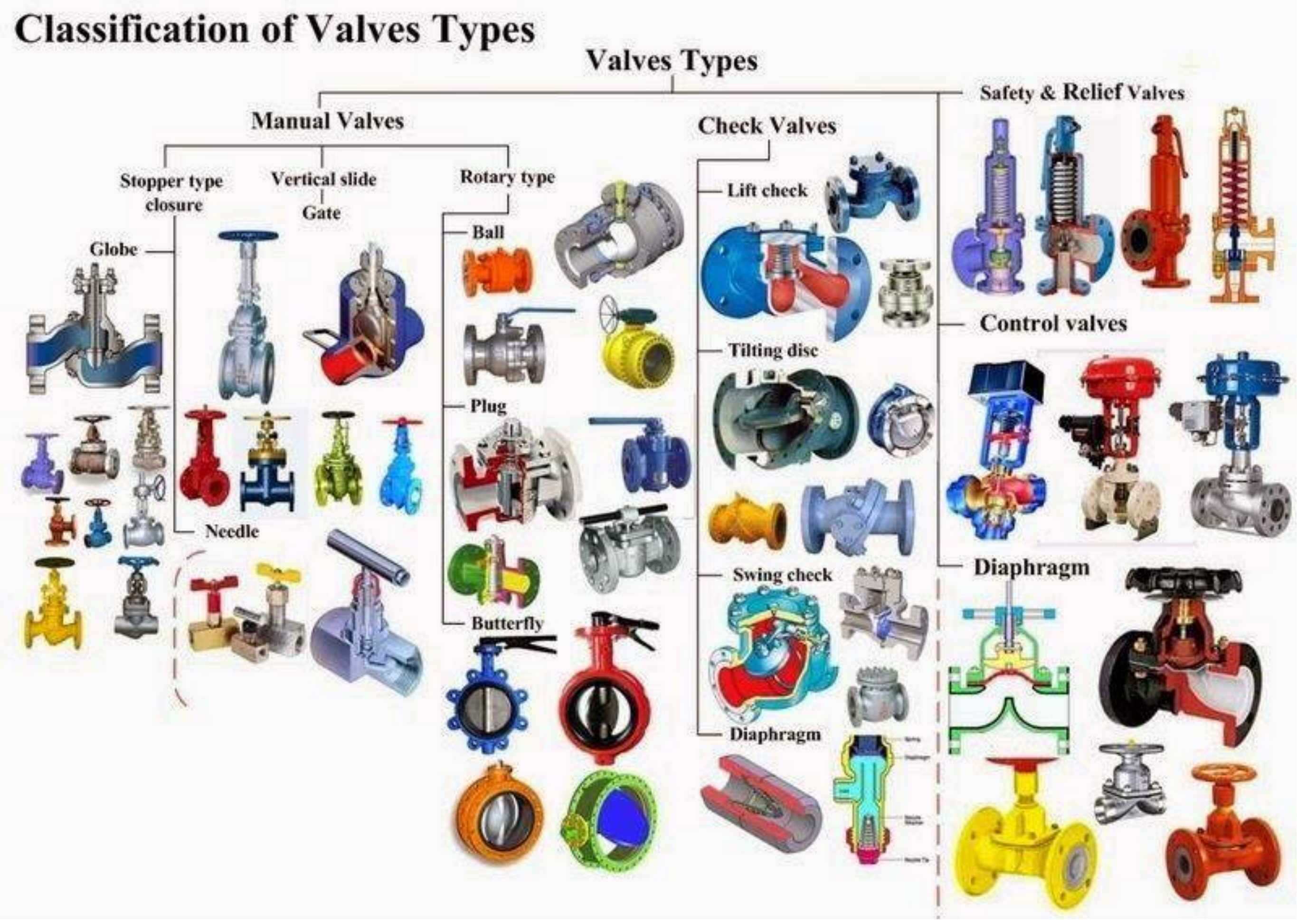
PG
PG
Drain
Water Pump


FLOATING HEAD Heat Exchanger

Handover & Final House Keeping ⟹ By Maintenance

- Remove tools and equipment
- Clean and wash the area
- ❑ Close Work permit
- ❑ Remove scaffold after unit start-up

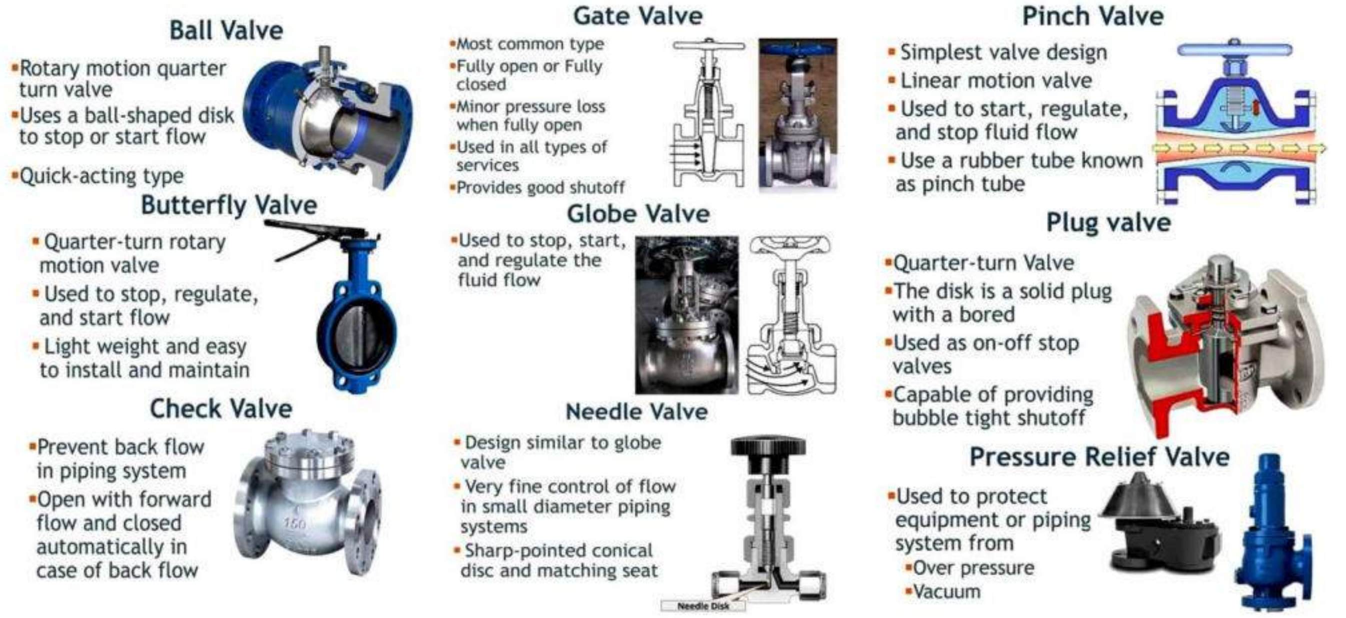
## VALVES


Classification of Valves Types
Valves Types
Manual Valves
Check Valves
Safety & Relief Valves
Stopper type closure
Vertical slide
Gate
Rotary type
Globe
Ball
Plug
Needle
Butterfly
Lift check
Tilting disc
Swing check
Diaphragm
Control valves
Diaphragm

**Mechanical devices that are used in industrial piping for…….**

The different types of valves used in industry suit any of the following applications:

1. Start/stop the flow of the fluid (hydrocarbons, oil & gas, steam, water, acids) through the pipeline (example: gate valve, ball valve, butterfly valve, knife gate valve, or plug valve)
2. Modulate the flow of the fluid through the pipeline (example: globe valve)
3. Control the flow of the fluid (control valve)
4. Change the direction of the flow (for example a 3-way ball valve)
5. Regulate the pressure of a process (pressure reducing valve)
6. Protect a piping system or a device (pump, motor, tank) from overpressures (safety or pressure relief) or back-pressures (check valve)


Needle Disk

**Ball Valve**
- Rotary motion quarter turn valve
- Uses a ball-shaped disk to stop or start flow
- Quick-acting type

**Butterfly Valve**
- Quarter-turn rotary motion valve
- Used to stop, regulate, and start flow
- Light weight and easy to install and maintain

**Check Valve**
- Prevent back flow in piping system
- Open with forward flow and closed automatically in case of back flow

**Gate Valve**
- Most common type
- Fully open or Fully closed
- Minor pressure loss when fully open
- Used in all types of services
- Provides good shutoff

**Globe Valve**
- Used to stop, start, and regulate the fluid flow

**Needle Valve**
- Design similar to globe valve
- Very fine control of flow in small diameter piping systems
- Sharp-pointed conical disc and matching seat

**Pinch Valve**
- Simplest valve design
- Linear motion valve
- Used to start, regulate, and stop fluid flow
- Use a rubber tube known as pinch tube

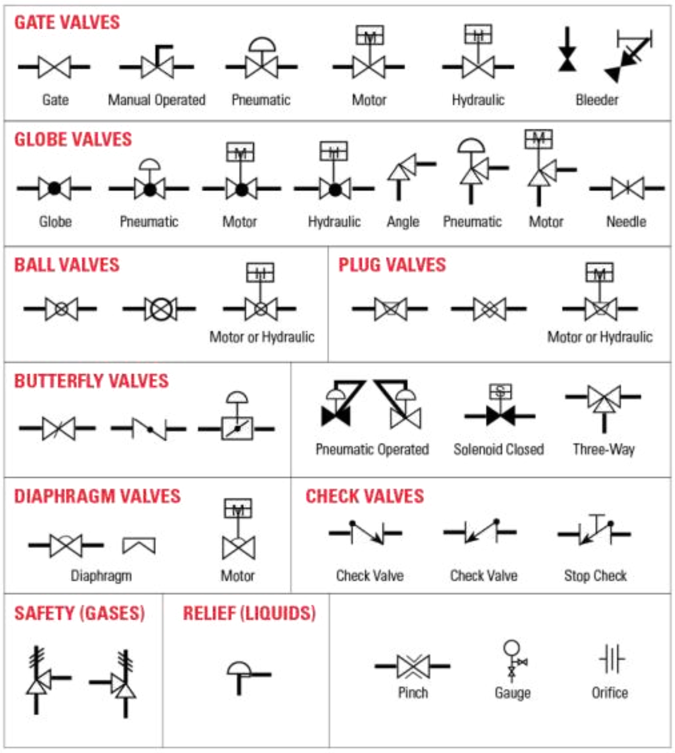
**Plug valve**
- Quarter-turn Valve
- The disk is a solid plug with a bored
- Used as on-off stop valves
- Capable of providing bubble tight shutoff

**Pressure Relief Valve**
- Used to protect equipment or piping system from
  - Over pressure
  - Vacuum

**VALVES BY DISC TYPE**

- LINEAR MOTION: gate, globe, diaphragm, pinch, and check valves
- ROTARY MOTION: butterfly, ball, plug, eccentric- and swing check valves
- QUARTER TURN: devices that require approximately a quarter turn motion, from 0 to 90° of the stem to move from fully close to a fully open position or vice versa.

## VALVE SYMBOLS:


GATE VALVES
Gate
Manual Operated
Pneumatic
Motor
Hydraulic
Bleeder
GLOBE VALVES
Globe
Pneumatic
Motor
Hydraulic
Angle
Pneumatic
Motor
Needle
BALL VALVES
Motor or Hydraulic
PLUG VALVES
Motor or Hydraulic
BUTTERFLY VALVES
Pneumatic Operated
Solenoid Closed
Three-Way
DIAPHRAGM VALVES
Diaphragm
Motor
CHECK VALVES
Check Valve
Check Valve
Stop Check
SAFETY (GASES)
RELIEF (LIQUIDS)
Pinch
Gauge
Orifice

It the part of the valve which generates the motive power. It is the mechanism which operates the valve plug, in correspondence to the control signal received from the controller.

➢**Actuators Types:**

- Pneumatic
  - Spring Diaphragm
  - Piston Cylinder
- Electrical
- Hydraulic

- **How the valves are classified based on their function & Types-sketches?**

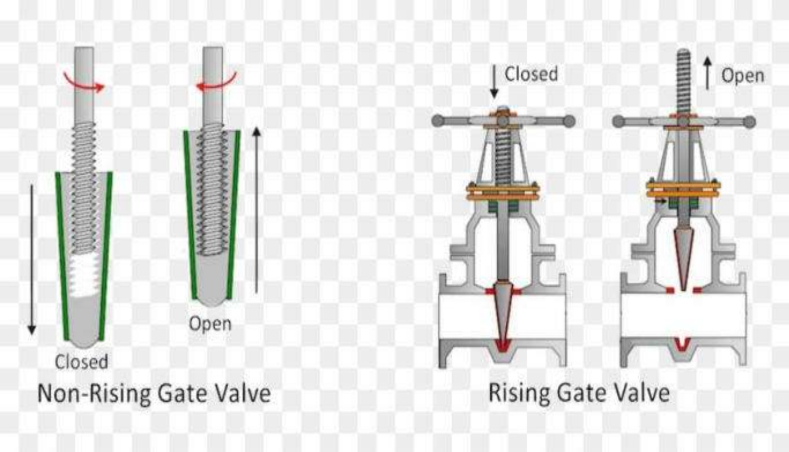
| A. **Isolation.** | B. **Regulation** | C. **Non- Return** | D. **Special purpose** |
|---|---|---|---|
| 1. Gate valve.<br>2. Ball valve<br>3. Plug valve.<br>4. Piston valve.<br>5. Diaphragm Valve.<br>6. Butterfly valve.<br>7. Pinch valve. | 1. Globe valve.<br>2. Needle valve.<br>3. Butterfly valve.<br>4. Diaphragm valve.<br>5. Piston valve.<br>6. Pinch valve | 1. Check valve. | 1. Multi- Port valve.<br>2. Flush Bottom valve.<br>3. Float valve.<br>4. Foot valve.<br>5. Line blind valve.<br>6. Knife Gate valve |

### Types of Valves:

**1. Gate Valve** A gate valve stops flow by placing a metal gate across the opening in the pipe. In the open position of the gate valve, the fluid flows through the valve in straight line without change of direction. Therefore resistance to the flow is minimum. Due to this reason pressure drop across a fully open gate valve is also minimum. Gate valves are not used in throttle condition, the gates gets eroded due to high velocity of the fluid and thus making positive shut off impossible upon closing.
The gate of the valve can be of different types such as solid wedge gate or parallel disc or solid split gate. There are mainly 2 types of gate valves based on the threading location on the valve stem,
**(i) Rising stem gate valve-** Here whenever valve is opened or closed, the stem of the valve will lift or go down

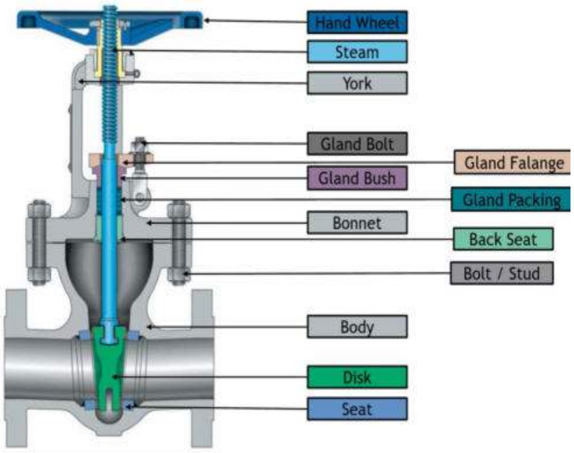
**(ii) Non-rising stem gate valve-** In a non-rising stem gate valve, the threading on the bottom of valve stem engages the gate and the gate rises and falls without the stem rising through the stuffing box.

**Advantage in the case of non-rising stem** is lesser space requirement as compare to rising stem type.
**Disadvantage in case of non-rising stem** one can never tell at a glance, whether or not a rising stem valve is open.


Closed
Open
Closed
Open

Non-Rising Gate Valve

Rising Gate Valve


Hand Wheel
Steam
York
Gland Bolt
Gland Bush
Bonnet
Body
Disk
Seat
Gland Falange
Gland Packing
Back Seat
Bolt / Stud

**2. Plug Valve**

Plug valves are also called as cocks. The port of this valve, which controls opening, is called as plug. Since a flow through a plug valve can be stopped by a quarter turn of plug, these are mainly used in services, which require quick closing and opening action. While flowing through a plug valve the fluid flows in straight line without changing direction, hence, resistance to flow and pressure drop across the valve is minimum. Since turning of plug causes friction, plug need to be lubricated to minimize its wear. Sometimes, if process fluid contamination with lubricant cannot be tolerated, non-lubricated valves of special materials must be used.

### 3. Globe Valve

When a fluid flows through a globe valve, there is a change of direction of flow. Due to this reason the resistance to flow and pressure drop across the valve are higher here than in the case of gate or plug valve. When a globe valve is partially open, the entire disc is exposed to the flow. Hence the wear or erosion of the disc is likely to be even. Due to this reason, positive shut off is possible with this valve even after long use. Therefore this valve can be used for throttling services. For the least pressure drop, a globe valve should be installed such that the flow is from the under the disc. Deposition of solid particles on the valve seat prevents the complete closing of the valve hence these valves cannot be used for handling slurries i.e. liquids containing solids.

### 4. Diaphragm Valves

These valves offer some advantages not possible with other valves. These provide smooth stream lined fluid passages without pockets. They can be used for flow control, leak tight closure and even with fluids carrying solid particles. Since only diaphragm comes in contact with process fluids, working mechanism of the valve prevents product contamination and corrosion of valve parts. Maintenance of the valve is easy and simple. They are used in process to overcome the problems of corrosion, abrasion, contamination, clogging, leakage etc.

### 5. Ball Valve

Like plug valves, these are also quick opening type valves. A quarter turn can open or close the valve. Valve seat can be made up of a wide variety of materials. Therefore these can be used over a wide range of temperatures as well as process fluid applications. Ball valves are non-sticking and provide tight closure. Pressure drop across the valve is very small. They are easy to repair and maintenance costs are low.

### 6. Butterfly valve

They are very simple in design. They are used to control or regulate fluid flow. The pressure drop across the valve is very small. Faster operation is possible with these valves i.e. they require only quarter turn from full open to fully closed position. However positive or total isolation is not possible with these valves.

### 7. Check Valve

Check valves permit flow in one direction and are used to prevent back flow in pipelines. They are also known as **n**on **r**eturn **v**alves or NRVs. Different types of check valves are used in industry. They are lift check valves, swing check valves, ball check valves.

### 8. Needle Valve

They are valves in which the seat of valve is like a pointed needle. These valves find use where very fine control is required for appreciably low flow they offer high differential pressure to flow of fluids

### 9. Three way Valves

They are simple gate valves in which the seat is so arranged that it can rotate in three directions. Theses valves find use for duplex filter changeover of duplex cooler changeover.

- **VALVE INSPECTION AND TESTING : ( API 598 )**

  The following tests and examinations are specified in this standard.

  a) Shell Test.
  b) Back Seat Test.
  c) Low Pressure Closure Test.
  d) High Pressure Closure Test.
  e) Visual Examination of Castings.

- **VALVE INSTALLATION GUIDE :**

  a) The height of the hand wheel of normal operating valve shall not be more than 1800 mm above operating level. As alternative permanent plat form may be provided.
  b) Maintenance valves more than 2000 mm above operating level for NPS 2” and larger shall be provided with chain operating.

  **Valve should not be positioned with their stem pointing down ward below horizontal with following exceptions :**

  ✓ No horizontally positioned stems in low temperature service.
  ✓ Butterfly valves shall not be installed with the spindle in the vertical position for services where collection of dirt in the lower shaft bearing could occur.
  ✓ Gate valves installed around safety / relief valves and in flare lines shall be positioned with the stem pointing horizontally.

**Where to place the valves :**

a) Preferably place valves in lines from headers (on pipe racks ) in horizontal rather than vertical runs, so that lines can drain when the valves are closed.
b) To avoid spooling unnecessary length of pipe, mount valves directly onto flanged equipment .
c) A relief valve that discharges into a header should be placed higher than the header in order to drain into it.
d) Locate heavy valves near suitable supports points. Flanges should not closer than 12 inches to nearest support, so that installation is not hampered.

**The ASME valve standard B16.34 is a globally accepted standard to design, manufacture and test valves used in the oil and gas industry. ASME B16.34 is also mentioned in the more general ASME spec ASME B31.1, “Power Piping Design”.**

A valve complies with ASME B16.34 when the following conditions are met:

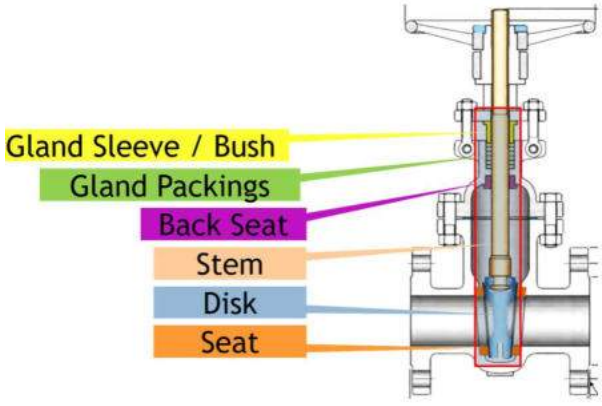
- The valves body & shell materials comply with ASME and ASTM material standards for chemistry and strength
- Body & shell materials are heat-treated to ensure proper grain structure, corrosion resistance, and hardness.
- Wall thicknesses of body and other pressure-containing components meet ASME B16.34 specified minimum values for each pressure class.
- NPT and SW end connections comply with ASME B1.20.1 or ASME B16.11.
- Stems are internally loaded and blowout proof.
- All bolting will be ASTM grade with maximum applied stress controlled by B16.34.
- Each valve is shell tested at 1,5x rated pressure for a specific test time duration.
- Each valve is tested for seat leakage in both directions for a specific test time duration.
- Each valve is permanently tagged with materials of construction, operating limits and name of the manufacturer.

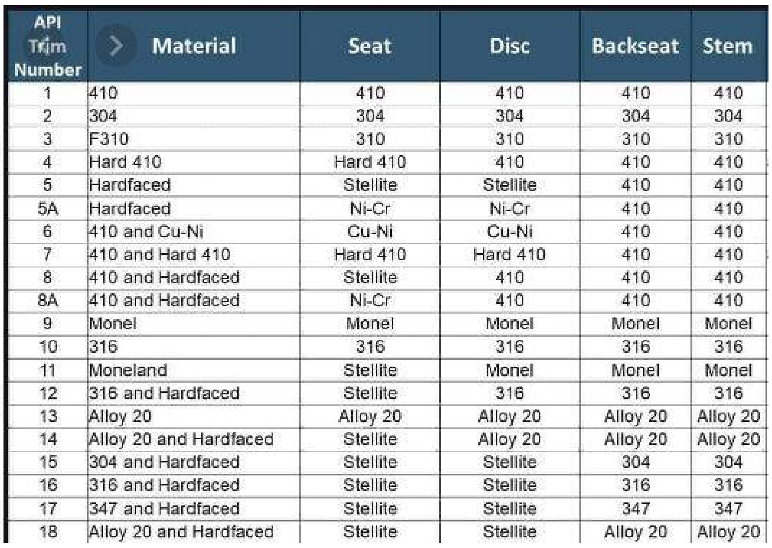
**Manufacturers of valves used in the oil and gas industry need to know the following information to supply the right device:**

- Valve type
- Bore size in NPS or DN
- Valve pressure rating (class range from 150# to 4500#)
- Specification (example API 6D, API 600, API 602, etc..)
- Body and trim materials (at least)
- Required end connection (flanged, threaded, butt weld …..etc)
- Fluid in the pipeline (>oil, gas, water, steam, solids)
- Working temperature and pressure
- Quantity
- Delivery time
- Origin restrictions (exmp. Chinese origins allowed or not …)

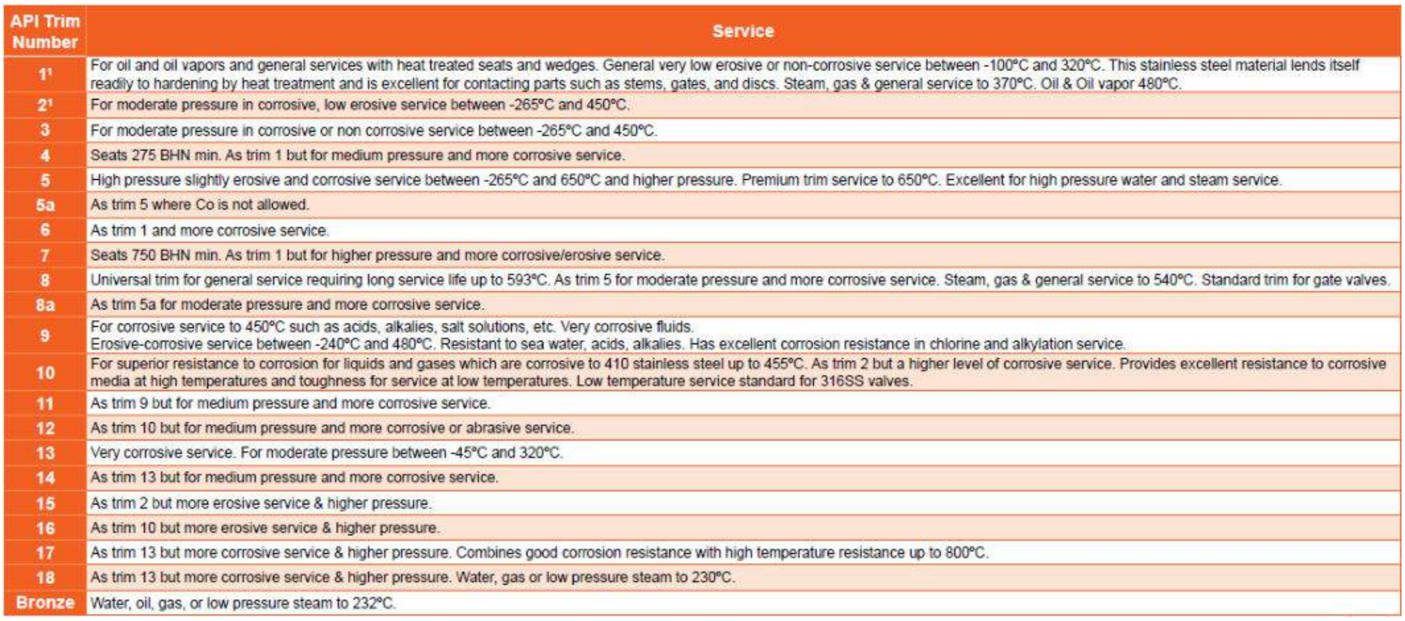
**What is valve trim?**

The operating parts of a valve which are normally exposed to the process fluid are referred to as 'valve trim'. Usually these parts are subject to wear and degradation and hence are replaceable. **Usually parts like stem, closure member, seating surface etc. are called as valve trim.** The parts such as body, bonnet, yoke etc. are not considered as trim (API 600)





| API Trim Number | Material | Seat | Disc | Backseat | Stem |
|---|---|---|---|---|---|
| 1 | 410 | 410 | 410 | 410 | 410 |
| 2 | 304 | 304 | 304 | 304 | 304 |
| 3 | F310 | 310 | 310 | 310 | 310 |
| 4 | Hard 410 | Hard 410 | 410 | 410 | 410 |
| 5 | Hardfaced | Stellite | Stellite | 410 | 410 |
| 5A | Hardfaced | Ni-Cr | Ni-Cr | 410 | 410 |
| 6 | 410 and Cu-Ni | Cu-Ni | Cu-Ni | 410 | 410 |
| 7 | 410 and Hard 410 | Hard 410 | Hard 410 | 410 | 410 |
| 8 | 410 and Hardfaced | Stellite | 410 | 410 | 410 |
| 8A | 410 and Hardfaced | Ni-Cr | 410 | 410 | 410 |
| 9 | Monel | Monel | Monel | Monel | Monel |
| 10 | 316 | 316 | 316 | 316 | 316 |
| 11 | Moneland | Stellite | Monel | Monel | Monel |
| 12 | 316 and Hardfaced | Stellite | 316 | 316 | 316 |
| 13 | Alloy 20 | Alloy 20 | Alloy 20 | Alloy 20 | Alloy 20 |
| 14 | Alloy 20 and Hardfaced | Stellite | Alloy 20 | Alloy 20 | Alloy 20 |
| 15 | 304 and Hardfaced | Stellite | Stellite | 304 | 304 |
| 16 | 316 and Hardfaced | Stellite | Stellite | 316 | 316 |
| 17 | 347 and Hardfaced | Stellite | Stellite | 347 | 347 |
| 18 | Alloy 20 and Hardfaced | Stellite | Stellite | Alloy 20 | Alloy 20 |



| API Trim Number | Service |
|---|---|
| 1[1] | For oil and oil vapors and general services with heat treated seats and wedges. General very low erosive or non-corrosive service between -100°C and 320°C. This stainless steel material lends itself readily to hardening by heat treatment and is excellent for contacting parts such as stems, gates, and discs. Steam, gas & general service to 370°C. Oil & Oil vapor 480°C. |
| 2[1] | For moderate pressure in corrosive, low erosive service between -265°C and 450°C. |
| 3 | For moderate pressure in corrosive or non corrosive service between -265°C and 450°C. |
| 4 | Seats 275 BHN min. As trim 1 but for medium pressure and more corrosive service. |
| 5 | High pressure slightly erosive and corrosive service between -265°C and 650°C and higher pressure. Premium trim service to 650°C. Excellent for high pressure water and steam service. |
| 5a | As trim 5 where Co is not allowed. |
| 6 | As trim 1 and more corrosive service. |
| 7 | Seats 750 BHN min. As trim 1 but for higher pressure and more corrosive/erosive service. |
| 8 | Universal trim for general service requiring long service life up to 593°C. As trim 5 for moderate pressure and more corrosive service. Steam, gas & general service to 540°C. Standard trim for gate valves. |
| 8a | As trim 5a for moderate pressure and more corrosive service. |
| 9 | For corrosive service to 450°C such as acids, alkalies, salt solutions, etc. Very corrosive fluids.<br>Erosive-corrosive service between -240°C and 480°C. Resistant to sea water, acids, alkalies. Has excellent corrosion resistance in chlorine and alkylation service. |
| 10 | For superior resistance to corrosion for liquids and gases which are corrosive to 410 stainless steel up to 455°C. As trim 2 but a higher level of corrosive service. Provides excellent resistance to corrosive media at high temperatures and toughness for service at low temperatures. Low temperature service standard for 316SS valves. |
| 11 | As trim 9 but for medium pressure and more corrosive service. |
| 12 | As trim 10 but for medium pressure and more corrosive or abrasive service. |
| 13 | Very corrosive service. For moderate pressure between -45°C and 320°C. |
| 14 | As trim 13 but for medium pressure and more corrosive service. |
| 15 | As trim 2 but more erosive service & higher pressure. |
| 16 | As trim 10 but more erosive service & higher pressure. |
| 17 | As trim 13 but more corrosive service & higher pressure. Combines good corrosion resistance with high temperature resistance up to 800°C. |
| 18 | As trim 13 but more corrosive service & higher pressure. Water, gas or low pressure steam to 230°C. |
| Bronze | Water, oil, gas, or low pressure steam to 232°C. |

## Refrigeration:

### Refrigeration basics:

- ✓ Refrigeration is the removal of heat from a material or space, so that its temperature is lower than that of its surroundings.
- ✓ When refrigerant absorbs the unwanted heat, this raises the refrigerant's temperature ("**Saturation Temperature**") so that it changes from a liquid to a gas — it evaporates. The system then uses condensation to release the heat and change the refrigerant back into a liquid. This is called "**Latent Heat**".
- ✓ This cycle is based on the physical principle, that a liquid extracts heat from the surrounding area as it expands (boils) into a gas.
- ✓ The refrigerant will be both a vapor and a liquid in the loop.
- ✓ "Saturation Temperature" – can be defined as the temperature of a liquid, vapor, or a solid, where if any heat is added or removed, a change of state takes place.

### Refrigeration cycle

**There are four main components in a refrigeration system:**

- ✓ The Compressor
- ✓ The Condensing Coil
- ✓ The Metering Device
- ✓ The Evaporator

Two different pressures exist in the refrigeration cycle. The evaporator is low pressure side and the condenser is high pressure side, these pressure areas are divided by the other two components. On one end, is the metering device which controls the refrigerant flow, and on the other end, is the compressor.

- **Compressor:** It compresses the low pressure refrigerant vapor from the evaporator and compresses it into a high pressure vapor. The inlet to the compressor is called the "Suction Line". It brings the low pressure vapor into the compressor. After the compressor compresses the refrigerant into a high pressure Vapor, it removes it to the outlet called the "Discharge Line". **Condenser** :

- ✓ The "Discharge Line" leaves the compressor and runs to the inlet of the condenser. Because the refrigerant was compressed, it is a hot high pressure vapor (as pressure goes up – temperature goes up).
- ✓ The hot vapor enters the condenser and starts to flow through the tubes. Cool air is blown across the outside of the finned tubes of the condenser (usually by a fan or water with a pump).Since the air is cooler than the refrigerant, heat jumps from the tubing to the cooler air (energy goes from hot to cold – "latent heat").
- ✓ As the heat is removed from the refrigerant, it reaches its "saturated temperature" and starts to "flash" (change states), into a high pressure liquid.
- ✓ The high pressure liquid leaves the condenser through the "liquid line" and travels to the "metering device". Sometimes running through a filter dryer first, to remove any dirt or foreign particles.

**Metering Devices:** Metering devices regulate how much liquid refrigerant enters the evaporator

- ✓ Common used metering devices are, small thin copper tubes referred to as "cap tubes", thermally controller diaphragm valves called "TXV's" (thermal expansion valves) and single opening "orifices".
- ✓ The metering device tries to maintain a preset temperature difference or "super heat", between the inlet and outlet openings of the evaporator.
- ✓ As the metering device regulates the amount of refrigerant going into the evaporator, the device lets small amounts of refrigerant out into the line and looses the high pressure it has behind it.
- ✓ Now we have a low pressure, cooler liquid refrigerant entering the evaporative coil (pressure went down – so temperature goes down).

### Thermal expansion Valves:

- ✓ A very common type of metering device is called a TXV Valve (Thermostatic Expansion Valve). This valve has the capability of controlling the refrigerant flow. If the load on the evaporator changes, the valve can respond to the change and increase or decrease the flow accordingly.
- ✓ Expansion valve. This is simply a very small hole between the high-pressure and the low pressure sides of the refrigerator/air conditioner.
- ✓ **The TXV has a sensing bulb attached to the outlet of the evaporator. This bulb senses the suction line temperature and sends a signal to the TXV allowing it to adjust the flow rate. This is important because, if not all, the refrigerant in the evaporator changes state into a gas, there could be liquid refrigerant content returning to the compressor**. This can be fatal to the compressor. Liquid cannot be compressed and when a compressor tries to compress a liquid, mechanical failing can happen. The compressor can suffer mechanical damage in the valves and bearings. This is called" **liquid slugging**".
- ✓ Normally TXV's are set to maintain 10 degrees of superheat. That means that the gas returning to the compressor is at least 10 degrees away from the risk of having any liquid.

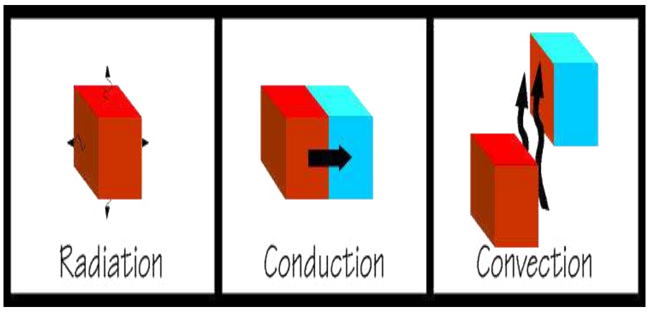
### The Evaporator:

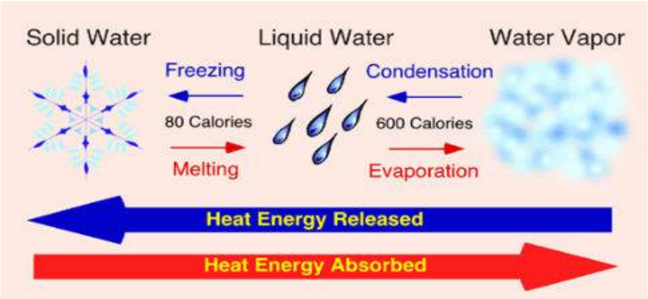
- ✓ The evaporator is where the heat is removed from your house, business or refrigeration box.
- ✓ Low pressure liquid leaves the metering device and enters the evaporator. Usually, a fan will move warm air from the conditioned space across the evaporator finned coils.
- ✓ The cooler refrigerant in the evaporator tubes, absorb the warm room air. The change of temperature causes the refrigerant to "flash" or "boil", and changes from a low pressure liquid to a low pressure cold vapor.

- ✓ The low pressure vapor is pulled into the compressor and the cycle starts over. The amount of heat added to the liquid to make it saturated and change states is called "**Super Heat**". One way to charge a system with refrigerant is by super heat.

- **What is the definition of 1 ton of refrigeration?** It is a unit in air conditioning and Refrigeration which is used to measured the capacity of a unit.....
  - ✓ One ton can be explained simply as removal of heat by a system required to melt one ton of ice in 24 hours
  - ✓ To be more technical it is equal to removal of 12000 BTU heat per hour (One **BTU** is the amount of heat energy we need to raise the temperature of one pound of water by one degree Fahrenheit.).
  - ✓ Removal of 3025 kcal heat per hour is called 1 ton of refrigeration.

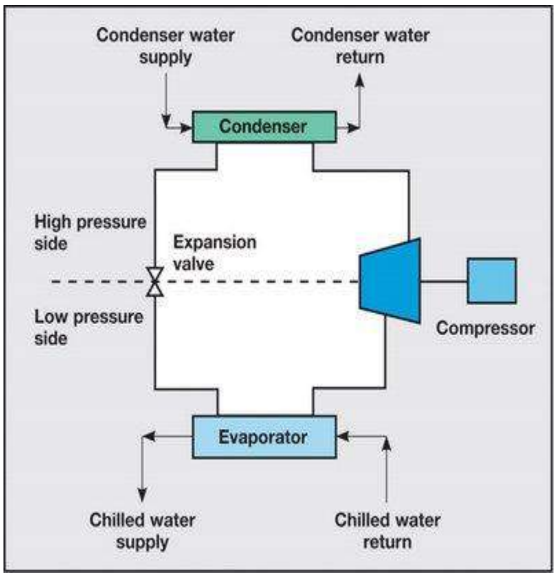
**How things get colder?**

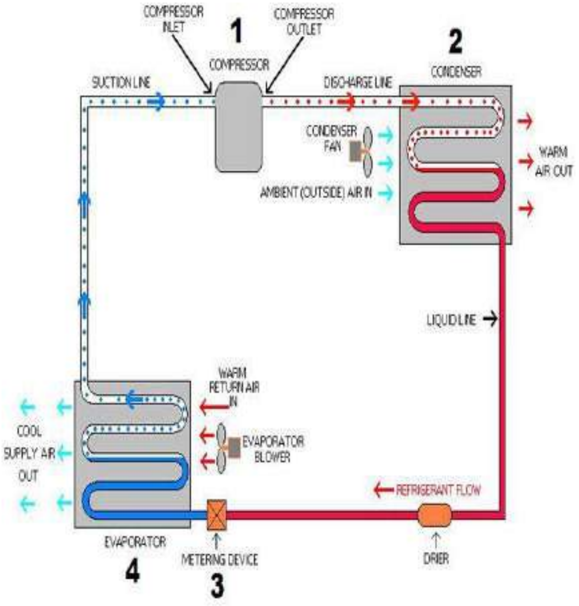

Radiation
Conduction
Convection


Solid Water
Liquid Water
Water Vapor
Freezing
80 Calories
Melting
Condensation
600 Calories
Evaporation
Heat Energy Released
Heat Energy Absorbed

If you place two objects together so that they remain touching, and one is hot and one is cold, heat will flow from the hot object into the cold object. This is called **conduction**. When heat is transferred by a substance in the gaseous state the process is called **convection**.

- **A C , DRYER , CHILLER DIAGRAMME**


Condenser water supply
Condenser water return
Condenser
High pressure side
Expansion valve
Low pressure side
Compressor
Evaporator
Chilled water supply
Chilled water return


COMPRESSOR INLET
1
COMPRESSOR OUTLET
COMPRESSOR
SUCTION LINE
DISCHARGE LINE
2
CONDENSER
CONDENSER FAN
AMBIENT (OUTSIDE) AIR IN
WARM AIR OUT
LIQUID LINE
WARM RETURN AIR IN
EVAPORATOR BLOWER
COOL SUPPLY AIR OUT
REFRIGERANT FLOW
EVAPORATOR
4
METERING DEVICE
3
DRIER

- **What is Dew point?**
  - ✓ It is the temperature at which the partial pressure of the water vapor in the mixture is equal to the vapor pressure of water.
  - ✓ The temperature where condensate formation will start upon constant cooling of vapor mixture.
  - ✓ Dew point is a saturation temperature. Dew point is always lower than or equal to the dry bulb temperature. Dew point is always lower than or equal to the wet-bulb temperature.
  - ✓ At 100% saturation: Dry bulb temperature = wet bulb temperature = Dew point.

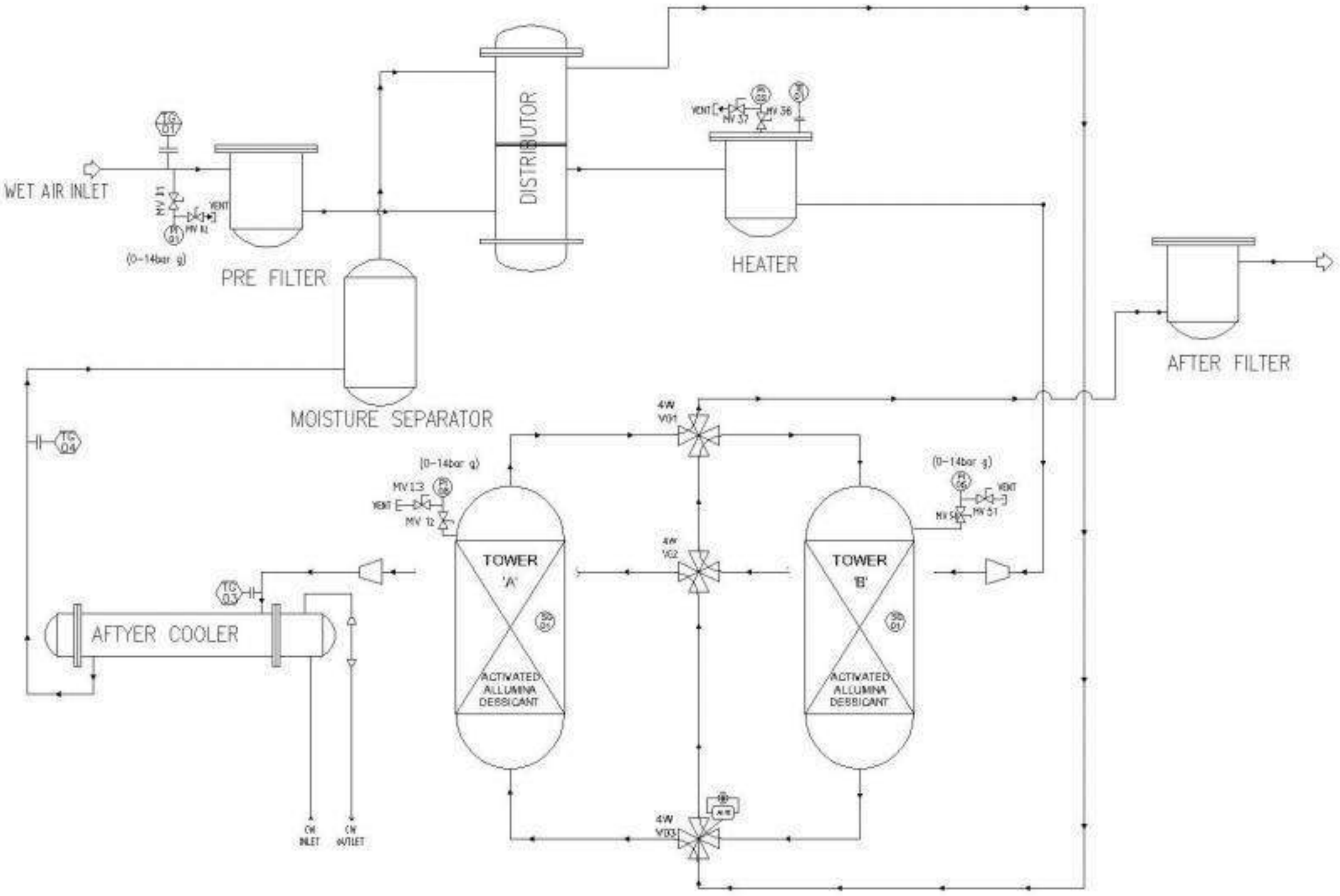
- **Refrigerant –**
- ✓ A substance which absorbs heat through expansion or vaporisation is known as refrigerant
- ✓ Any substance that transfers heat from one place to another, creating a cooling effect.
- **Types-** ammonia, carbon dioxide ,sulphur dioxide,Freon-11,Freon 12

**Types of dryer -**1) refrigeration type 2) adsorption type

**Factors to be consider for selection of dryer**

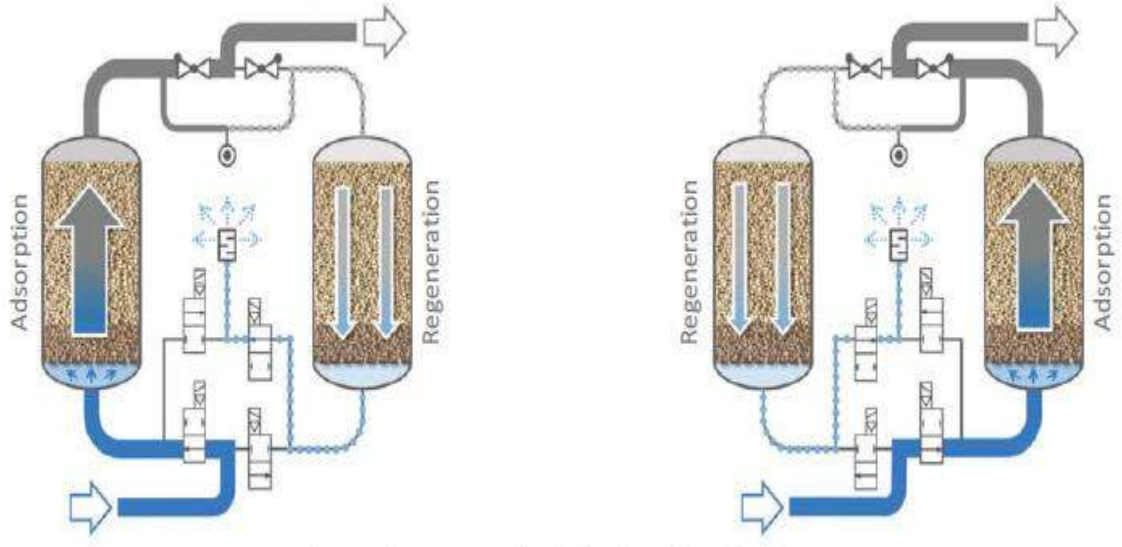
1) degree of dryness (dew point)
2) Energy consumption
3 ) Pressure drop across dryer
4 ) Flow rate through dryer
5) Site condition
6) inlet pressure / outlet pressure
7) Types of dryer

### **Adsorption type Air dryer circuit:**


WET AIR INLET
TG 01
MV 11
PI 01
VENT
(0–14bar g)
PRE FILTER
DISTRIBUTOR
VENT
MV 37
MV 36
HEATER
MOISTURE SEPARATOR
AFTER FILTER
TG 04
4W V01
4W V02
4W V03
(0–14bar g)
MV 13
VENT
MV 12
TOWER 'A'
ACTIVATED ALLUMINA DESSICANT
TOWER 'B'
ACTIVATED ALLUMINA DESSICANT
(0–14bar g)
VENT
MV 51
TG 03
AFTYER COOLER
CW INLET
CW OUTLET

## Adsorption dryer

### Design and function

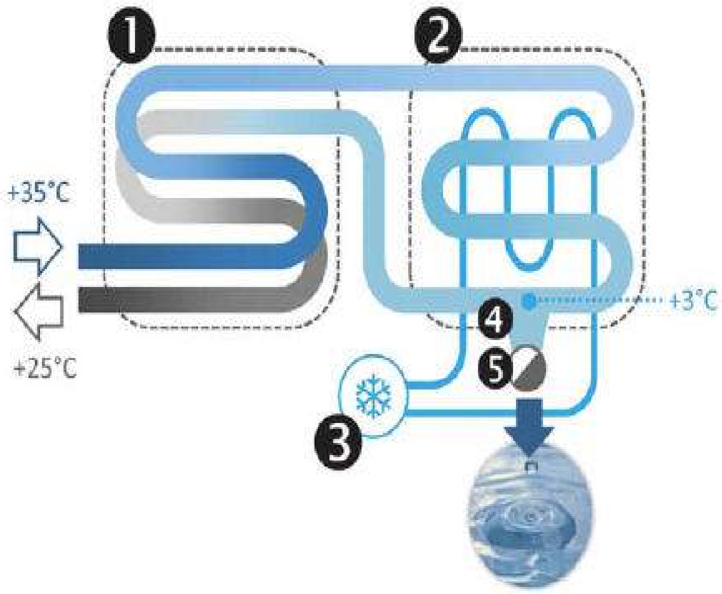

Adsorption
Regeneration
Regeneration
Adsorption

Images show an example of a heatless adsorption dryer

Adsorption dryers consist of two pressure vessels, which are both filled with desiccant and are alternately operated via switch-over. The compressed air to be dried flows through a vessel where the moisture is thoroughly removed by the desiccant (**adsorption**). At the same time, the moisture stored in the desiccant in the second vessel is removed (**regeneration**). If the desiccant in the vessel in which adsorption takes place is saturated with moisture then the vessels are switched and the process begins again. One complete run of adsorption and regeneration in a vessel is called a **cycle**, and the time required is the **cycle time**.

# Refrigeration dryer

## Design and function


1
2
+35°C
+25°C
+3°C
4
5
3

Refrigeration dryers consist of two heat exchangers and a controlled refrigerant circuit.

The compressed air flowing in is pre-cooled in the first heat exchanger, the air-to-air heat exchanger ❶, by the compressed air in counterflow direction, which is already cooled and flowing out.

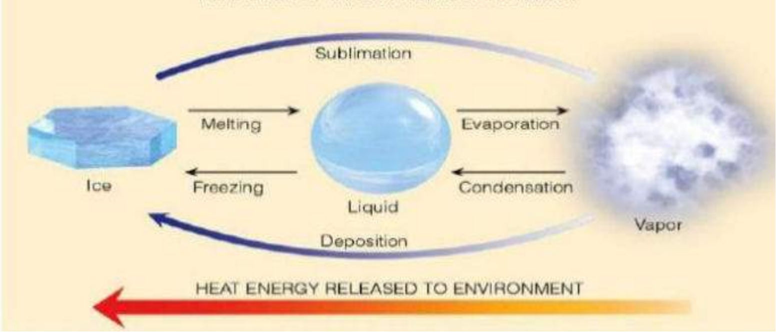
In the second heat exchanger, the refrigerant-to-air heat exchanger ❷, the compressed air is cooled down to its minimum temperature by the connected refrigerant circuit ❸.

During the entire cooling process, moisture in the compressed air precipitates in the form of condensate which is centrally collected ❹ and automatically discharged ❺.

Finally, using the air-to-air heat exchanger ❶, the compressed air is heated again by the warm, incoming compressed air in counterflow direction and thus brought to an undersaturated state. Provided that the compressed air temperature does not fall below the pressure dew-point, no more condensate can arise.

### **What is sublimation?**

☐ Sublimation is the process where a solid changes phase and turns directly into gas without passing through a liquid phase.


HEAT ENERGY TAKEN FROM ENVIRONMENT
Sublimation
Melting
Evaporation
Ice
Freezing
Condensation
Liquid
Vapor
Deposition
HEAT ENERGY RELEASED TO ENVIRONMENT

## Column:

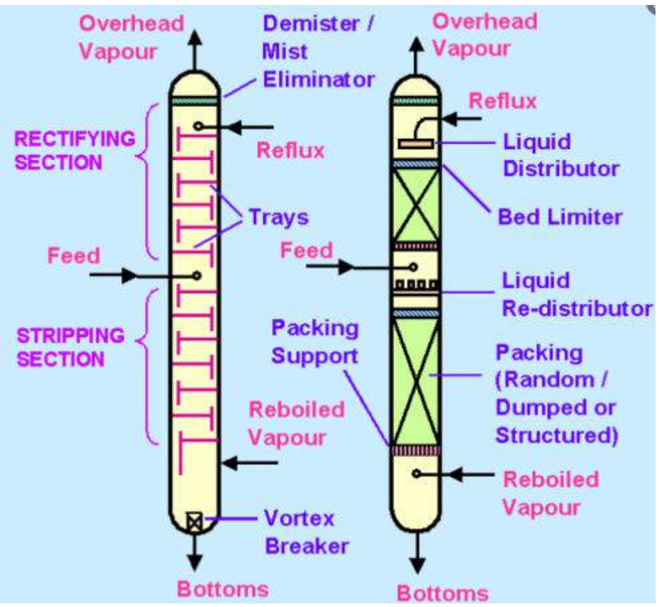
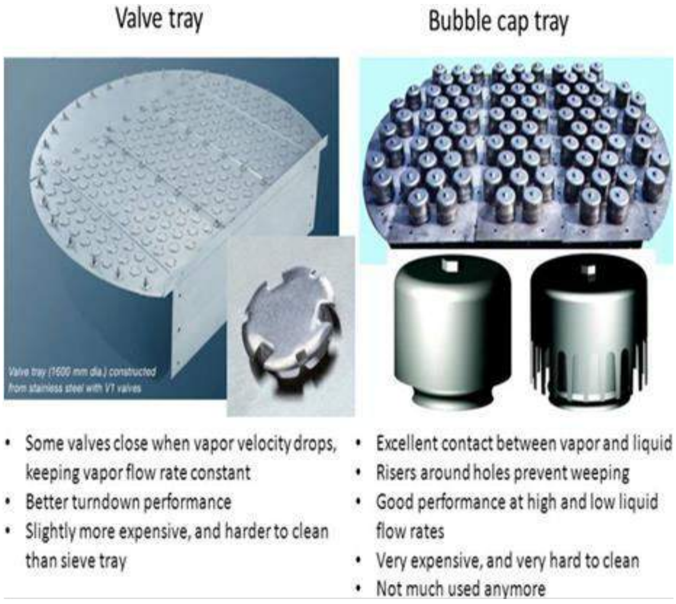
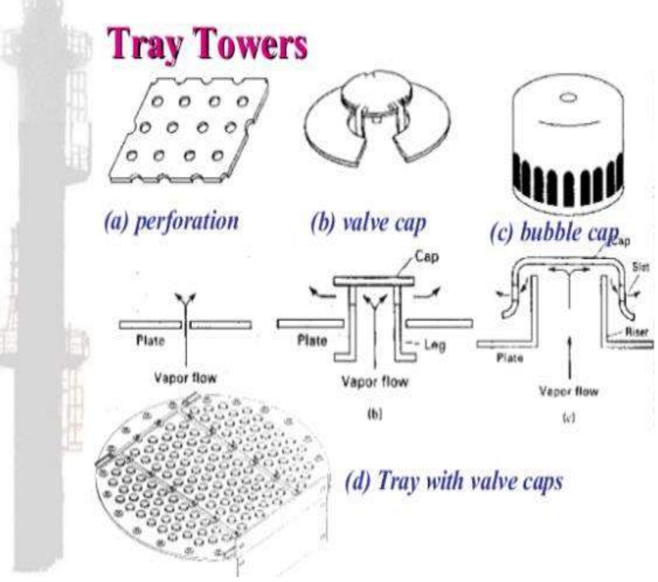

Overhead Vapour
Demister / Mist Eliminator
Overhead Vapour
RECTIFYING SECTION
Reflux
Reflux
Liquid Distributor
Trays
Bed Limiter
Feed
Feed
Liquid Re-distributor
STRIPPING SECTION
Packing Support
Packing (Random / Dumped or Structured)
Reboiled Vapour
Reboiled Vapour
Vortex Breaker
Bottoms
Bottoms

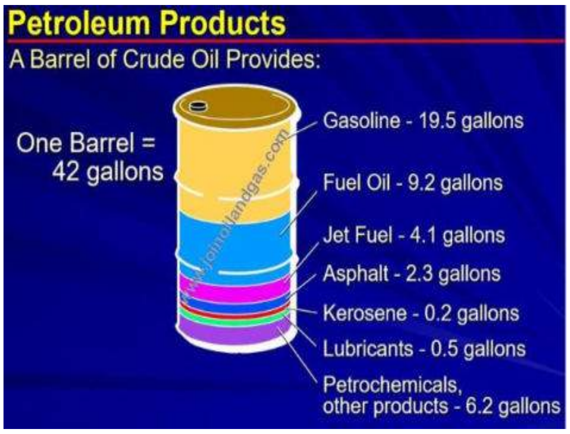
**Plate & packed column**


Valve tray
Bubble cap tray
Valve tray (1600 mm dia.) constructed from stainless steel with V1 valves

- Some valves close when vapor velocity drops, keeping vapor flow rate constant
- Better turndown performance
- Slightly more expensive, and harder to clean than sieve tray

- Excellent contact between vapor and liquid
- Risers around holes prevent weeping
- Good performance at high and low liquid flow rates
- Very expensive, and very hard to clean
- Not much used anymore


Tray Towers
(a) perforation
(b) valve cap
(c) bubble cap
Cap
Cap
Slot
Plate
Plate
Leg
Riser
Plate
Vapor flow
Vapor flow
Vapor flow
(b)
(c)
(d) Tray with valve caps



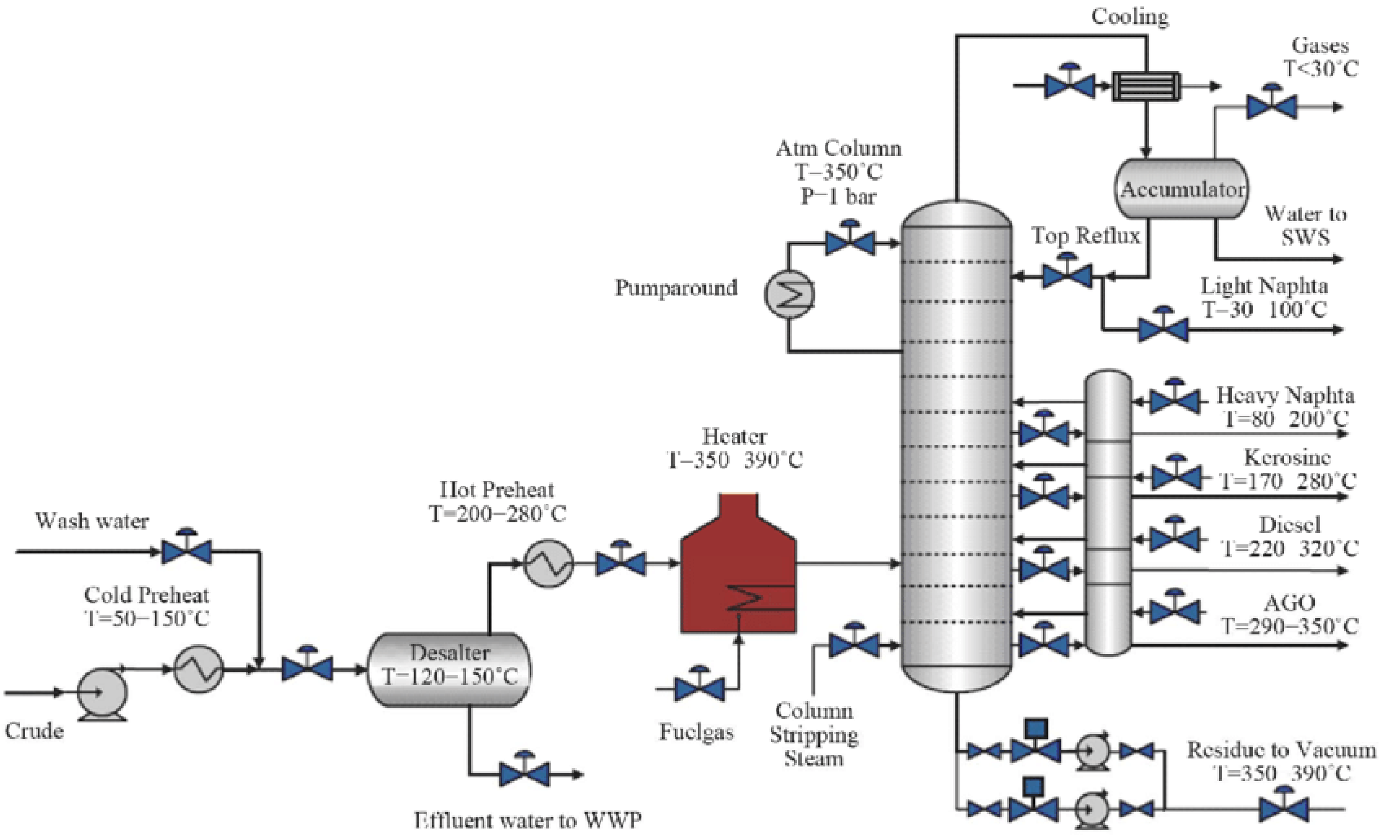
Petroleum Products

A Barrel of Crude Oil Provides:

One Barrel = 42 gallons

- Gasoline - 19.5 gallons
- Fuel Oil - 9.2 gallons
- Jet Fuel - 4.1 gallons
- Asphalt - 2.3 gallons
- Kerosene - 0.2 gallons
- Lubricants - 0.5 gallons
- Petrochemicals, other products - 6.2 gallons

## CRUDE DISTILLATION UNIT (CDU):


Cooling
Gases T<30°C
Atm Column T~350°C P~1 bar
Accumulator
Water to SWS
Top Reflux
Pumparound
Light Naphta T~30 100°C
Heavy Naphta T=80 200°C
Heater T~350 390°C
Kerosine T=170 280°C
Hot Preheat T=200–280°C
Diesel T=220 320°C
Wash water
AGO T=290–350°C
Cold Preheat T=50–150°C
Desalter T~120–150°C
Crude
Fuelgas
Column Stripping Steam
Residue to Vacuum T=350 390°C
Effluent water to WWP

**What is Distillation?** A Process Where the lighters fluid is separated from the heavier fluid. Distillation is the separation technique and there are basically two main types of chemical treatments in distillation columns; one is for corrosion control and the second is fouling control. Several general factors influence the corrosion or fouling potential of a distillation process. These include feedstock, temperatures, reboiler heat fluxes, and hydrocarbon residence time. The type of feedstock for a distillation column has a large influence on the fouling potential .

**There are a least four types of chemical treatments in the process industry distillation**….

1. Antifoulants which include dispersants, inhibitors, metal deactivators, retardants, antiscalants, and antipolymerants
2. Corrosion Inhibitors which include neutralizers, and both nitrogen and nonnitrogen-based filming corrosion inhibitors
3. Phase Separation Chemicals which include emulsion breakers, defoamers, antifoams, extraction aids, and solids-settling aids.
4. Scavengers which include agents to remove sulfides, oxygen, peroxide, and carbonyls.

## Types of Columns

The vapors and liquid contact can be performed in different ways in a column. Based on this there are two types of column:

1. **Plate or Tray column**
2. **Packed column**

### 1. Plate or Tray columns

Plate column may further be divided into three types:

#### A. BUBBLE CAP COLUMN

Here the column is divided in sections by means of horizontal plates. Each plate carries a number of short nipples covered by bell shaped caps. Vapors from the plate rise through the nipples, diverted downward by the caps, comes out through the slots and finally bubbles out through the pool of liquid on the plate. Liquid flows across the plate through the down comer to the next plate below.

**B SIEVE PLATE COLUMNS** In this type also the column is divided into a number of sections by plates. Each plate having a number of perforations or sieves. The liquid in this column flows across the plate, over the weir and through the down comer to the next plate below. While the vapours from the plate rise through the sieves of the plate.

#### C. VALVE TRAY COLUMNS

Valve tray columns are modified version of sieve trays with lift with valves provided on the sieves of the plates. In the case of sieve tray columns, the liquid instead of flowing through the down comers, may drain through the sieves when the rising vapour velocity is very low. This possibility is minimized in valve tray columns as the valves prevent the liquid flow through the sieves.

### 2. Packed Column

In a packed column, the column is filled with some sort of suitable material, which offers a large surface area for the intimate contract of liquid and vapours. Different types of packing can be used to fill a packed column. They are: Raschig rings , Pall rings , Intalox saddle etc.

Packing arrangement inside a column is further classified as **random packing** and **stacked packing.**

- **Random packing** is one where packing are directly into the column and individual pieces of packing are not arranged in any particular pattern.
- **Stack packing** is one where the packings are arranged in a particular pattern. Stack packing gives lower pressure drop compared to random packing and hence normally wins over random packing, even though it is costlier one.
- **Vane Separator** It is basically a set of plates, having configuration of vanes, through the vapors/Gas passes vanes knock out the entrained moisture
- **Demister Pads** They are woven pads of wire mesh, used to knock down the entrained liquid in a stream of Gas or Vapour
- **Distributors** They are the devices used to uniformly and evenly expose the liquid/Gas/Vapour through packed beds, so that there is no short circuit.
- **Chimney Tray** This is a tray that has a provision to hold a pool of liquid and also to allow vapour/Gas to pass through it and liquid to come from top and flow down over a weir.
- **Vortex Breaker** They are mechanical devices that disable the formation of vortex through a pool of liquid, otherwise the vapour or gas will pass through this vortex.
- **Impingement Plate** It is a mechanical device, normally a plate, installed on the way of a fluid. They are useful in removing the entrained liquid from Gas/ Vapour and also to lessen the severity of erosion caused by high velocity fluid
- **Risers** They are lift-able caps on a chimney plate, used to allow gas/vapors to rise through pool of liquid. These caps sit down, when there is no flow of gas/vapors.
- **Down comer's -**They are mechanical devices that allow liquids to drain from an upper plate to lower plate, without allowing vapours /Gas to pass. They provide a liquid seal for gas/vapor to pass.

**Flooding** refers to a condition in which liquid backs up over the tray or packed bed, hence increasing the liquid hold up.

- **Cause of flooding -** Flooding will take place if the amount of liquid flowing down and or the amount of vapour rising up are excessively large. When the liquid flow rate down the column increases, the liquid level in the down comer gradually rises and finally the level becomes flooding during the operation. Other causes of column flooding are foaming of liquid, plugging of tray sieves or down comers by dirt, polymers etc. and thereby resisting the free flow of liquid or vapours in the column.

- **Effect of flooding** In a flooding column since the resistance to vapour flow increases the pressure drop across the tray and across the column increases rapidly. In the flooded condition of operation, the column separation efficiency goes low and maintaining product quality and operation condition becomes difficult. Frequent flooding or prolonged operation in flooded condition may lead to disturbed packing or plates of the column.
- **Countermeasures**

  Operation of flooded column, during operation, can be normalized by any or all of the following action:

✓ Reduce feed to the column
✓ Reduce reflux to the column
✓ Reduce heating load of the column

**Channeling** In the case of packed columns the upward rising vapours or gases, contacts uniformly with the liquid down flowing across its surface. Sometimes some flow paths in the packing allow the liquid to flow while following a least resistance path. This phenomenon is called **Channeling** when it takes place it affects the mass transfer poorly.

- **Effects of Channeling:**
  - ✓ Due to the channeling effect, proper distribution of liquid in a packed column becomes difficult.
  - ✓ Due to channeling effect the Separation efficiency of a packed column gets reduced.
- **How to avoid Channeling?**
  In packed columns of considerable size or height it is necessary to put redistribution partition which collects liquid from the walls and returns it to the center of the column again

**FOAMING**

This is another typical phenomenon that process like ours needs to encounter. Foaming is basically a phenomenon by virtue of which the liquid in a Plate or Packed column produces froth (Soap bubble type)

**What causes Foaming?**

Foaming is normally caused by:
- Presence of oils in liquids
- Particulate material in the liquid
- Corrosion products in the liquid
- Presence of materials like oil in liquids
- Certain salts that reduce surface tension of the liquid.

**Why Foaming is harmful?**

1. As foam is floating above the pool of liquid owing to its lesser density, it tries to occupy the vapor space of the instrument taps. Hence the indicated values of readings like Level indication, Delta P indication etc are not dependable
2. The gas, while flowing upwards through a column (Plate type or Packed type), picks up this foam and takes it from lower plates (or packing) to upper plates (or packing), Thereby the purified material on top gets contaminated by less impure material of bottom (plates or packing). Thereby the rectification process gets totally disturbed

**How to control foaming?**

We do not have any other option than controlling foaming, as Process cannot live with it. Following are some of the measures that are taken as a guard…..
- Continuous/Intermittent filtration of the particulate materials in the solution
- Avoiding Corrosion phenomena in the system, thereby eliminating particulate generation
- Avoid oils in the solutions
- Feed Antifoam to the foaming solution

**What is Fouling?**

**Distillation** column **fouling** service is a broad term that encompasses many **fouling** phenomena. The **fouling** phenomena can occur in the vapor or liquid phase. If the **fouling** occurs in the liquid phase, chemical inhibitors can help reduce or eliminate the **fouling**.

**Common Column Issues**

- Fouling – Multiple factors, either independently or together can cause fouling tendencies in columns. Vaporization of volatile chemicals, droplet formation from condensation, and corrosion-inducing chemical reactions are just some of the phenomena that occur inside a column, making the packing and other internal components susceptible to fouling.
- Mechanical Issues – Equipment vibrations can cause column components to shift over time or even cause mechanisms within the columns to come apart, resulting in damage to the internal structures.
- Internal Pressure Reduction – Reduced separation efficiency can result from low vapor flow which leads to a drop in pressure inside the column. If the pressure exerted by the vapor is insufficient, it won't hold up the liquid on the tray, resulting in the leakage of liquid through the column internal's perforations. This is known as "weeping" and can be detrimental to the purity of your distillation, sometimes requiring the batch to be reprocessed.
- Foaming - Although it is not as prevalent as other issues, foaming can occur in situations when the liquid expands and changes into vapor or gas at too high of a velocity and evaporation

rate. Design, condition and placement of the trays in the column can also attribute to the foaming problem. In fact, if trays are too close together, entrainment can occur (i.e. foaming fluid in a lower tray mixes with the liquid on the above tray).

## Column Repair / cleaning Work

**ISOLATION & preparation:**

- Isolation: De-pressurize column and Isolate all valves of those pipelines connected with column and do spading as per operation requirement.
- Arrange for Scaffolding , insulation removal , hose connection , blower , air eductor/ejector , fan , lightning , compressor , dehumidifier
- Check spares - tray , valve , gasket , studs ..etc.

**2. DE-GASSING**

- Open the man ways, keep it open 24 hours for natural degassing.
- Arrange air eductor , fan ..etc.. after removal of man way cover .
- After 24 hours start degassing with air eductors.
- Steaming from operation
- Once LEL become 0% then obtain confined space entry permit to enter inside for cleaning.
- Check VOC with the VOC gas monitor, if VOC is less than 15% can work without full face mask. But more than this level cleaning should be carried out with full face mask (organic cartridge).

**3. Column CLEANING**

- Cleaning team inside column should have multi-gas detector for monitoring the LEL during cleaning.
- Open internal man way of tray inside column
- Removal of oily water and sludge..etc.
- Clean all tray , cap , valves ..etc. for inspection.
- Clean / inspect / replace chemical injection quill & nozzle

**4. Column inspection / repair**

- Check all tray for looseness , crack , damage , support ..etc..
- Check all valves , cap ,fittings , stud/bolts , clean or replace if require
- Check internal support , structure , column inside wall , nozzle ..etc..- repair if require .

**5 . Box up**

## Lubricants

**Significance:** As the viscosity of the oil increases, so does the density of the material, as a higher density results in oil that is less likely to respond to flow or other movement. Thus, an oil or lubricant with a viscosity grade of 220 is thicker and more solid-like than oil with a VG of 100 or 68. The grade is a literal measurement of the oil's ratio of absolute viscosity in centipoises (a unit of measurement) to the density, also known as centistokes.

**Grades:** Since its inception in 1975, the organizations have developed 20 viscosity gradients to cover the range of oils and lubricants that are common in hydraulic application. The lowest common ISO grade is 32 and the scale ranges up to 220. The scale also includes grades 46, 68, 100 and 150. Because the viscosity of oil and other liquids is dependent upon temperature, the ISO grade is only applicable at a specific temperature. Base ISO grades are calculated when the oil is at a temperature of 40 degrees C (104 degrees F) and raising or lowering the temperature of the material will alter the oil's resistance to movement such as flow. For example, raising the temperature to 100 degrees Celsius will change the number of centistokes from a grade to just 5.4 centistokes, in comparison to the 32 centistokes at 40-degrees Celsius. At this temperature, the oil is more likely to be effected by flow.

### WHY LUBRICATION?

In principle, any two surfaces moving against each other cause mutual wear and generate heat through frictional resistance. Engineering surfaces are rough at micro-scale. Consequently, they only touch at a few points called "Asperities" and at these points, the pressures can reach extremely high values.

If there is relative movement between the surfaces, the pressure breaks down the surface oxide film and the virgin surfaces weld together at the points of contact. When the movement continues, these welds are broken causing wear and dissipation of energy as heat. The combination of heat and wear has a cascading effect and within a short time it results in a complete breakdown of the material.

The purpose and object of Lubrication is to introduce a lubricant film between the two surfaces in order to prevent direct metal to metal contact. The performance of the lubricant is measured by the friction reducing properties resulting in,

1. Reduction in power consumption and
2. Reduction in premature machine breakdown.

### FUNCTIONS OF LUBRICATION:

1. To reduce friction between two metal surfaces.
2. To carry out heat generated due to friction.
3. To act as a seal against contamination.
4. To resist corrosion of the machine parts.
5. To cleanse the working parts off oxidation, acidification etc.

### BENEFITS OF GOOD LUBRICATION:

1. Reduced power consumption.
2. Lower machine breakdowns.
3. Lower maintenance costs.
4. Increased machinery life.
5. Increased productivity due to reduced plant downtime.

### Advantages of Grease over oils:

1. Less frequent application since it retains in the bearing for a longer time.
2. Acts as a seal or retainer hence does not require oil seal or lip seal arrangement.
3. No dripping or spattering like oils, so the surrounding area remains clean.
4. Better rust or corrosion protection.
5. Wider range of operating temperatures up to as high as 500°F.
6. It minimizes starting friction.
7. Highly suitable for excessive bearing internal clearances.

### Disadvantages of Grease over oils:

1. Greases are not as good coolant as oils.
2. It is less easy to change or replace.
3. Greases cannot flush out contaminators.

**It is very essential to carry out a plant survey for lubrication that involves following things:**

1. Examining the machines and other such equipment's that need regular lubrication.
2. Listing of the parts of the machines to be lubricated.
3. Studying the manufacturer's recommendations and instructions regarding lubrication.
4. Considering the operating environment (elevated temperatures, moisture etc.)
5. Analysing the actual behaviour of the machine.
6. Deciding the frequency of lubrication.

Choice of lubricants is primarily determined by the operating speed and temperature. Under normal operating conditions, grease can normally be used. Grease is easily retained in the bearings and it protects the bearing from moisture and impurities. Grease is oils with thickeners, generally in the form of metallic soaps.

- Calcium base grease =for up to +6o$^0$c
- Sodium base grease =for temp from-30°C to +80°C Lithium base grease =for temp from -30°C to 110$^0$c
- Lead soap additives to prevent water penetration.

**Requisite grease quantity (in grams),**
**G=0.005DB,** where, D=bearing OD in mm,
B=bearing width in mm, and G=grease in grams.

Oil is recommended where speeds and temperature are high and heat generated is to be conducted away. All high speeds, oils of low viscosity may be used to keep bearing temp down, whereas at low temp, highly viscous oils must be used to ensure that a sufficiently thick film of lubrication is formed.

## OBJECTIVES OF LUBRICATION:

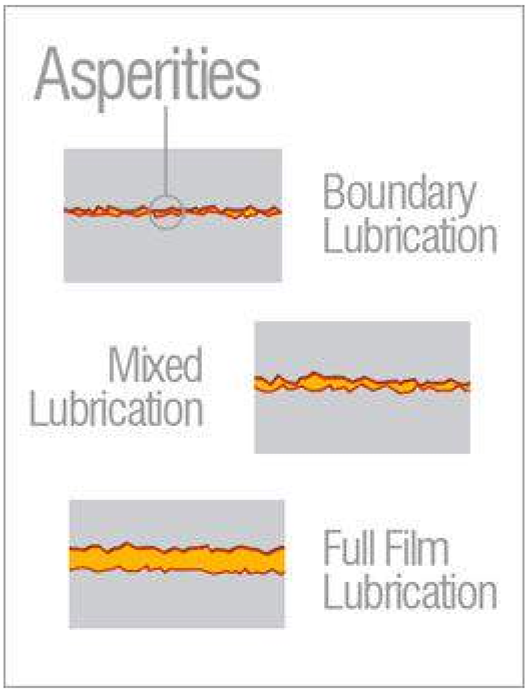
1) To reduce machine downtime and operating costs substantially (Downtime Reduction Strategy).
2) To correctly manage lubricants in sumps and reservoirs.
3) To optimize lubricant storage and handling procedures.
4) To design a safe and efficient storage area.
5) To implement "Oil Reclamation" to reduce consumption of lubricants.
6) To catch bearing faults with "Wear Debris Analysis".
7) To chalk out cost reducing strategies using oil analysis.
8) To implement modem oil analysis teamed with vibration and thermography (Reliability Centered Maintenance).
9) To select right lubricant with correct viscosity.
10) To understand the importance of proper lubrication. _
11) To know when to use Synthetic Lubricant.

### Types of Lubrication

There are three different types of lubrication: boundary, mixed and full film. Each type is different, but they all rely on a lubricant and the additives within the oils to protect against wear.

**Full-film lubrication** can be broken down into two forms: hydrodynamic and elastohydrodynamic. Hydrodynamic lubrication occurs when two surfaces in sliding motion (relative to each other) are fully separated by a film of fluid.

**Elastohydrodynamic lubrication** is similar but occurs when the surfaces are in a rolling motion (relative to each other). The film layer in elastohydrodynamic conditions is much thinner than that of hydrodynamic lubrication, and the pressure on the film is greater. It is called elastohydrodynamic because the film elastically deforms the rolling surface to lubricate it.



Even on the most polished and smooth surfaces, irregularities are present. They stick out of the surface forming peaks and valleys at a microscopic level. These peaks are called asperities. In order for full-film conditions to be met, the lubricating film must be thicker than the length of the asperities. This type of lubrication protects surfaces the most effectively and is the most desired.

**Boundary lubrication** is found where there are frequent starts and stops, and where shock-loading conditions are present. Some oils have extreme-pressure (EP) or anti-wear (AW) additives to help protect surfaces in the event that full films cannot be achieved due to speed, load or other factors.

These additives cling to metal surfaces and form a sacrificial layer that protects the metal from wear. Boundary lubrication occurs when the two surfaces are contacting in such a way that only the EP or AW layer is all that is protecting them. This is not ideal, as it causes high friction, heat and other undesirable effects.

**Mixed lubrication** is a cross between boundary and hydrodynamic lubrication. While the bulk of the surfaces are separated by a lubricating layer, the asperities still make contact with each other. This is where the additives again come into play.

- **What do the abbreviations "ISO VG" stands for?**
  The ISO: International Organization for Standardization issued a regulation known as "ISO 3448 Liquid Industrial Lubricants" that classifies lubricants on the basis of their kinematic viscosity value at 40°C (expressed in mm2/sec). Different numbers mark different **ISO VG (VG=Viscosity Grade**) levels coming close to its viscosity interval value.

✓ **Why and when should we buy high-cost synthetic lubricants?**
In reality, synthetic lubricants guarantee technological improvements. As regards their cost higher if compared with traditional lubricants mineral based it depends by the considered base; polyalphaolefines, esters, silicones, polygliycolis, perfluorinepoliyetheris, polyisobutylenes etc.
-improved fluidity at low temperatures
-improved oxidation-resistance at high temperatures
-reduced viscosity changes due to temperature variations
-improved biodegradability
-improved chemical compatibility with rubber and plastic compounds
-improved chemical inertia
-reduced evaporation
-lower risks of forming of harmful compounds during use
-increased ageing-resistance

- **Do lubricants have an expiration date?**
  There is no international technical regulations that codify expiration periods. The onset of any problems linked to using an aged lubricant depends mainly on its formulation typology; great care should be given to the product condition in its original package.
  **You can also consider these physical aspects and changes as a sign of non use:**
  -**grease**: abundant oil that floats on the top surface
  -**soluble oils**: noticeable separating of compounds or the presence of strong smells
  -**solvent products**: base concentration with solvent separated or evaporated
  -**lubricating oils**: noticeable separating of compounds or additive precipitation
  Even if there are no particular problems regarding expiration date, you should always keep lubricants in a dry storage room, in the original packages and use the aged products first.
- **FOLLOWING LUBRICANTS USED IN NORMAL CONDITION…… :**

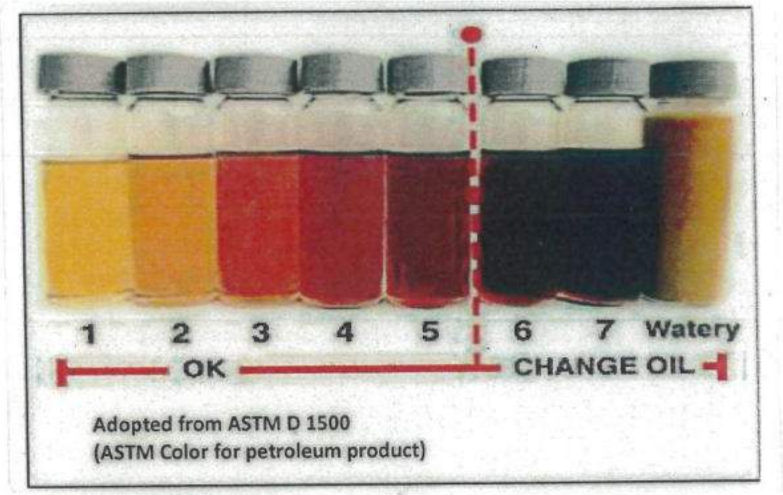
✓ For compressor --ISO VG 150
✓ For pump –ISO VG 68 (for process pump) & ISO VG 46 (For utility pump)
✓ Metering pump – ISO VG 100
✓ Rotary pump – ISO VG 220
✓ Blower – ISO VG 220
✓ Gearbox – 320 / 220

**Types of grease:**

✓ Sodium soap grease –suitable for high temp – 260 F
✓ Calcium soap grease - for high temp – 150 F
✓ Lithium soap grease - suitable for high temp – 260 F
✓ Calcium complex grease - suitable for high temp – 360 F
✓ Non soap grease - suitable for high temp – 500 F

**Fahrenheit to Celsius : (32°F − 32) × 5/9 = 0°C**

**Lube oil change chart:**



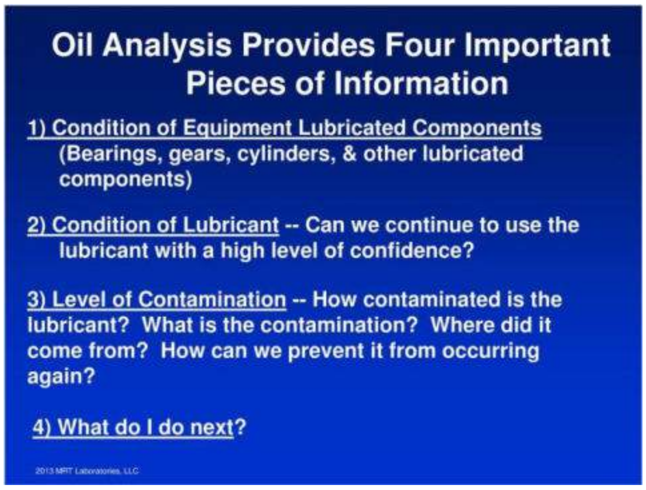
Adopted from ASTM D 1500
(ASTM Color for petroleum product)

## Oil analysis :

**Oil analysis** (OA)is the laboratory analysis of a lubricant's properties, suspended contaminants, and wear debris. OA is performed during routine predictive maintenance to provide meaningful and accurate information on lubricant and machine condition. By tracking oil analysis sample results over the life of a particular machine, trends can be established which can help eliminate costly repairs. The study of wear in machinery is called tribology (**Tribology** is the science and engineering of interacting surfaces in relative motion. It includes the study and application of the principles of friction, lubrication and wear). Tribologists often perform or interpret oil analysis data.

**OA can be divided into three categories:**

- ✓ analysis of oil properties including those of the base oil and its additives,
- ✓ analysis of contaminants,
- ✓ analysis of wear debris from machinery,



Oil Analysis Provides Four Important Pieces of Information

1) Condition of Equipment Lubricated Components (Bearings, gears, cylinders, & other lubricated components)

2) Condition of Lubricant -- Can we continue to use the lubricant with a high level of confidence?

3) Level of Contamination -- How contaminated is the lubricant? What is the contamination? Where did it come from? How can we prevent it from occurring again?

4) What do I do next?

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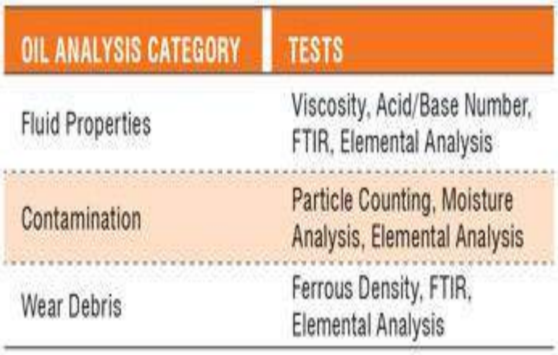


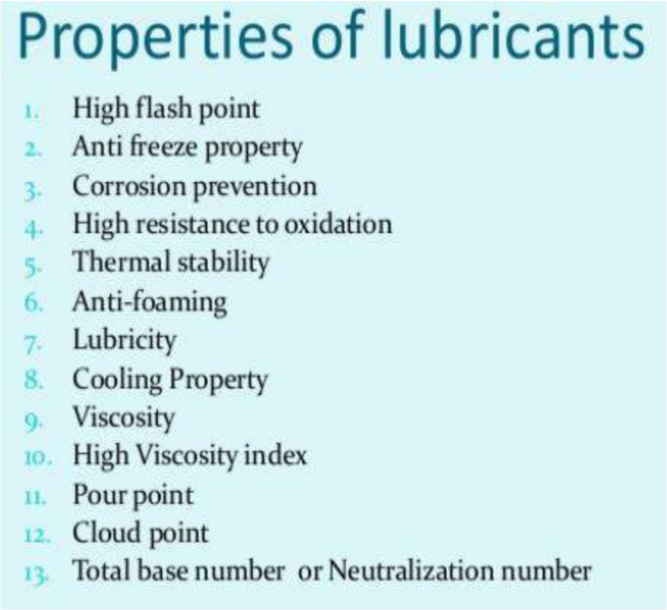
| OIL ANALYSIS CATEGORY | TESTS |
|---|---|
| Fluid Properties | Viscosity, Acid/Base Number, FTIR, Elemental Analysis |
| Contamination | Particle Counting, Moisture Analysis, Elemental Analysis |
| Wear Debris | Ferrous Density, FTIR, Elemental Analysis |

## What are the benefits? -

| | |
|---|---|
| ✓ Reduced downtime | 50-80% |
| ✓ Reduced maintenance costs | 50-80% |
| ✓ Increased machine life | 20-40% |
| ✓ Productivity increased | 20-30% |
| ✓ Profit increased | 25-60% |

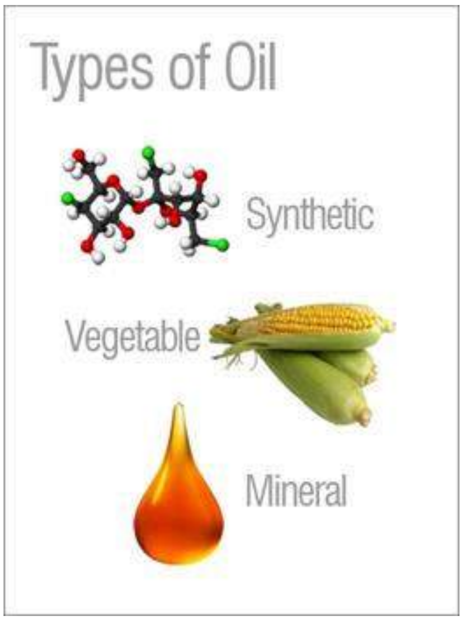
## Oil analysis can be applied to equipment utilization, maintenance and management:

- ✓ Utilization : Increase margins of operational safety , Increase availability by decreasing downtime , Increase overall component lifespan , Control standby equipment and replacement part requirements , Decrease fuel and oil consumption
- ✓ Maintenance : Identify and measure lube contamination and component wear , Eliminate unnecessary overhauls or inspections , Reduce in-service failures and field repairs , Establish proper lubricant service intervals
- ✓ Management : Improve cost assessment and control for equipment, labor and materials , Improve equipment record-keeping procedures, Evaluate equipment designs / applications, Reveal faulty operator practices

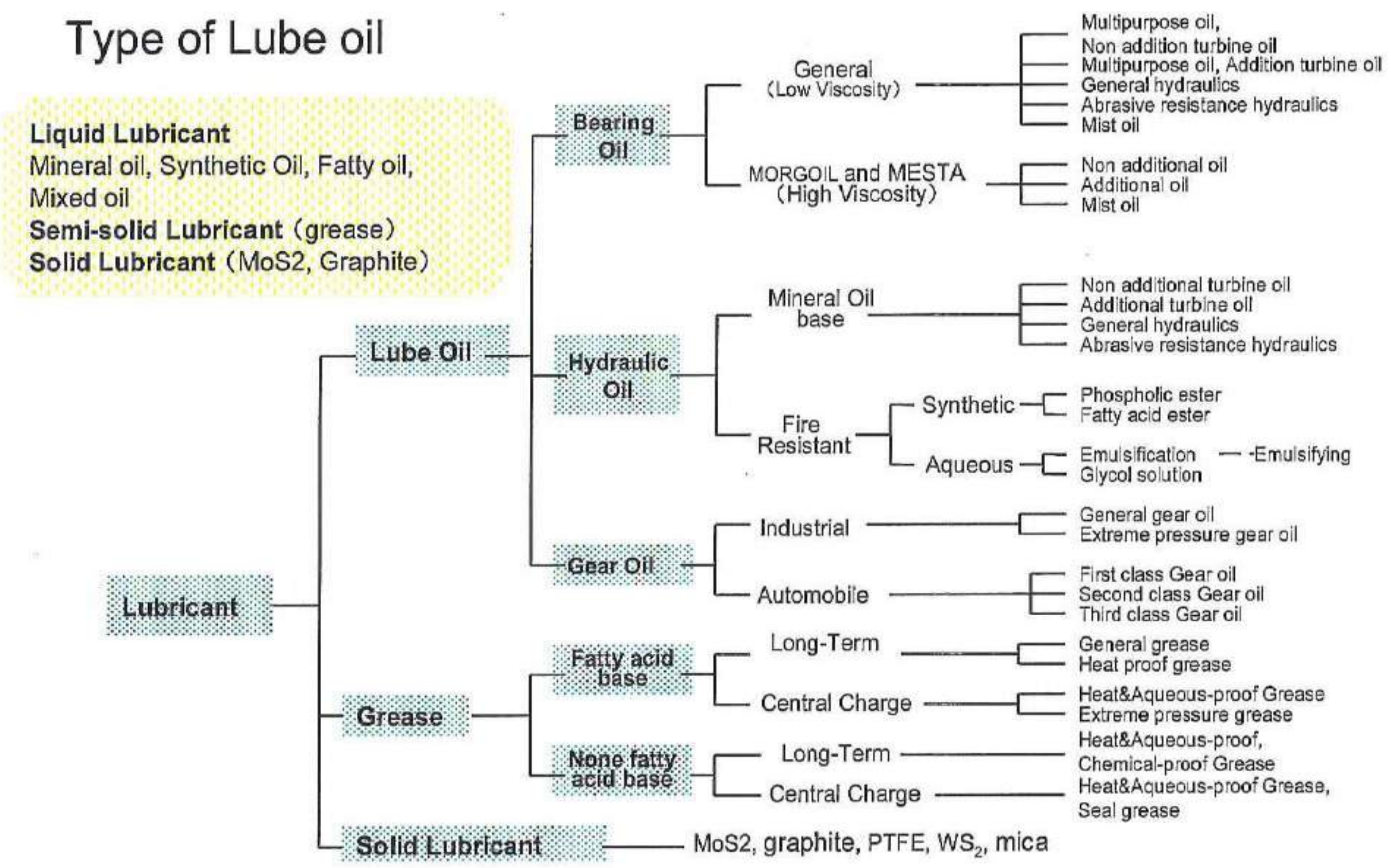


Properties of lubricants

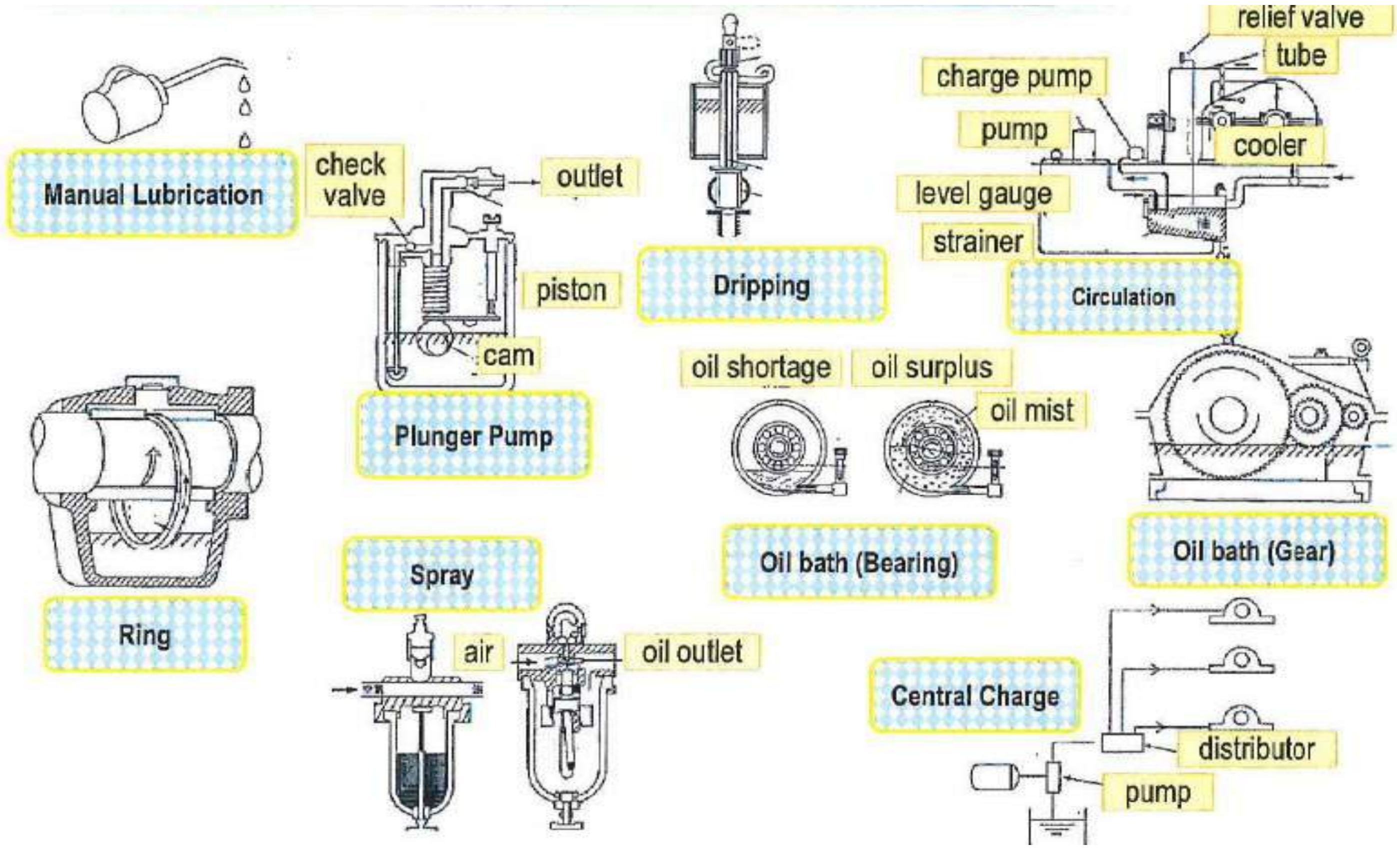
1. High flash point
2. Anti freeze property
3. Corrosion prevention
4. High resistance to oxidation
5. Thermal stability
6. Anti-foaming
7. Lubricity
8. Cooling Property
9. Viscosity
10. High Viscosity index
11. Pour point
12. Cloud point
13. Total base number or Neutralization number



# Type of Lube oil


Liquid Lubricant
Mineral oil, Synthetic Oil, Fatty oil, Mixed oil
Semi-solid Lubricant (grease)
Solid Lubricant (MoS2, Graphite)
Lubricant
Lube Oil
Bearing Oil
General (Low Viscosity)
Multipurpose oil, Non addition turbine oil
Multipurpose oil, Addition turbine oil
General hydraulics
Abrasive resistance hydraulics
Mist oil
MORGOIL and MESTA (High Viscosity)
Non additional oil
Additional oil
Mist oil
Hydraulic Oil
Mineral Oil base
Non additional turbine oil
Additional turbine oil
General hydraulics
Abrasive resistance hydraulics
Fire Resistant
Synthetic
Phospholic ester
Fatty acid ester
Aqueous
Emulsification
-Emulsifying
Glycol solution
Gear Oil
Industrial
General gear oil
Extreme pressure gear oil
Automobile
First class Gear oil
Second class Gear oil
Third class Gear oil
Grease
Fatty acid base
Long-Term
General grease
Heat proof grease
Central Charge
Heat&Aqueous-proof Grease
Extreme pressure grease
None fatty acid base
Long-Term
Heat&Aqueous-proof, Chemical-proof Grease
Central Charge
Heat&Aqueous-proof Grease, Seal grease
Solid Lubricant
MoS2, graphite, PTFE, WS2, mica

## TYPES OF LUBRICATION METHOD :


Manual Lubrication
check valve
outlet
piston
cam
Plunger Pump
Dripping
relief valve
tube
charge pump
pump
cooler
level gauge
strainer
Circulation
oil shortage
oil surplus
oil mist
Oil bath (Bearing)
Oil bath (Gear)
Ring
Spray
air
oil outlet
Central Charge
distributor
pump

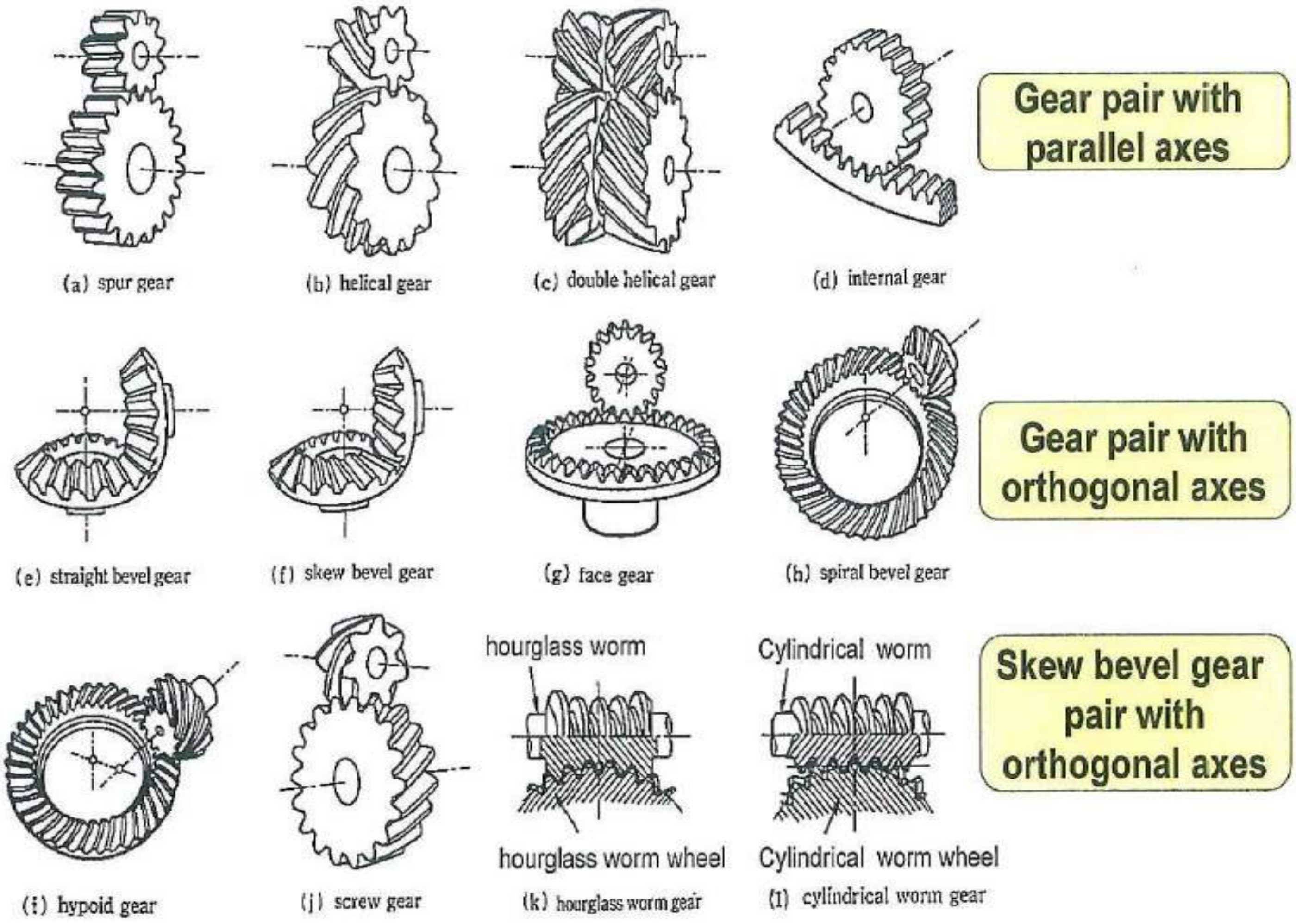
## Gears & Gearbox's –

**Gears** – whenever exact velocity ratio is require between two shafts or when distance between two shafts is too small toothed wheel called gears are used. To transmit rotary motion or power from one shaft to another are called gears, the smaller of gear pair called pinion and bigger is gear.

### Gear Ratios

Gear ratio is a number, usually expressed as a decimal fraction, representing how many turns of the input shaft cause one revolution of the output shaft. It applies to transmission, power take off, power dividers and rear axles. It can be defined as the ratio between numbers of teeth on the meshing gears. If the input gear is turning faster than the output gear, the system is said to have **power ratio**. If the input gear is turning slower than the output gear then the system is said to have a **speed ratio**.

In simple gear arrangement, the gear ratio can be simple calculated by looking at the number of teeth on the two gear wheels. It can also be calculated by dividing the tooth count of ring gear to the tooth count of pinion gear, carry out to 2 decimal points. The diameter of the gear wheel can also be calculated. A high gear ratio implies a high torque.


(a) spur gear
(b) helical gear
(c) double helical gear
(d) internal gear
Gear pair with parallel axes
(e) straight bevel gear
(f) skew bevel gear
(g) face gear
(h) spiral bevel gear
Gear pair with orthogonal axes
(i) hypoid gear
(j) screw gear
hourglass worm
hourglass worm wheel
(k) hourglass worm gear
Cylindrical worm
Cylindrical worm wheel
(l) cylindrical worm gear
Skew bevel gear pair with orthogonal axes

## Gearbox Repair Specifications

**1. All speed reducers or assemblies will be:**

- ✓ Completely disassembled.
- ✓ Hot Tank Stripped.
- ✓ Cleaned, wire brushed of all rust and grease.
- ✓ Inspected and/or tested as follows:
    - Measure all "fits" and compare with original drawing dimensions. Provide photographs and/or sketches for assembly.
    - Cases, housings, etc. - will be visually inspected for cracks and other signs of wear.
    - Shafts & Gearing - visually inspect and dimensionally checked, for possible reuse.

**2. A detailed line of all work required to recondition the assembly/speed reducer will be prepared and include:**

- ✓ Listing of any new parts required.
- ✓ Summary of required procedures to return reusable parts to print specification.
- ✓ Summary of price for labor and all materials to complete the job.

## Repair Specifications:

### 1. Fits

- All fits will be returned to original size and relative centers using either; plating, sleeving and/or welding and machining as per approved drawing.

### 2. Shafting

- Repair may be made by plating and grinding, or machining and sleeving.
- Will be straight and finished in accordance with tolerances and finish specifications as indicated on appropriate drawings.
- New shafting provided will match the specifications and dimensions of the original part as per customer print.
- Exposed threads, shaft ends and couplings will be protected with an anti-rust protection coating prior to shipping Gear Box.

### 3. Gearing

- Will be dimensionally inspected, manufacturers' prints, or reverse engineered.
- New gearing provided will meet or exceed the specifications and dimensions of the original parts.

### 4. Cases, Housing, etc.

- Fits - All fits will be returned to original size and relative centers using either; sleeving and/or welding and machining as approved
- All bolts, studs, pipe plugs, and other fittings will be removed and the holes re-tapped as necessary.
- Bolts, studs, and pipe fittings may be reused if in good condition.
- Replacement bolts, studs, and pipe fittings will be of equivalent grade and material unless otherwise specified.

### 5. Assembly and Test Procedures

- All seals, shims, and gaskets will be replaced
- All bearings will be replaced.
- All hardware will be reused or replaced depending upon condition.
- All repaired and overhauled units will be run tested to check contact patterns, clearances, backlash, and freedom of movement.

### 6. Painting and Identification

- All speed reducers will have:
    - Exterior surfaces cleaned of all loose scale and rust.
    - Entire Housing surfaces cleaned of all dirt and oil.
    - One coat of light blue enamel applied on the exterior, unless otherwise specified by the customer.
    - A new identification tag will be installed to each overhauled speed reducer with the following information:
        - Date overhauled
        - Our job number
        - Your purchase order number

### 7. Shipment

- All openings are properly protected with plugs or cover.
- All units are shipped dry; the unit shall be marked to indicate that lubricant must be added prior to operation.

### Run Test Procedure

- Firmly mount gearbox to be tested to run test stand.
- Attach the oil pumping station to the unit if required.
- Hook up all run test equipment.
- Check and document temperature.
- Start test motor and set variable RPM to the gearbox requirements.
- Attach gearbox to test motor and record decibel reading during run test.
- Check all sealed areas for any oil leakage.
- Gearbox bearing temperature will be checked and documented at several intervals during testing.
- Vibration and other nondestructive testing as per requirements / std.

### Gearbox maintenance - lubrication & vibration analysis

Gearbox repair, equally important is discovering the root cause of the gearbox failure in order to avoid unplanned machine downtime in the future. To pinpoint equipment failure, perform oil analysis, vibration measurements and thorough visual inspection, for instance examination of abrasive wear patterns and gear tooth pitting.

### Root Cause Failure Analysis

Identifying causes of gearbox failure is a crucial step in preventing future equipment problems. To determine failure root cause, perform both oil analysis and vibration analysis combined with visual inspections. These diagnostic techniques are usually required to monitor the condition of plant machinery and to control the causes of machine failure.

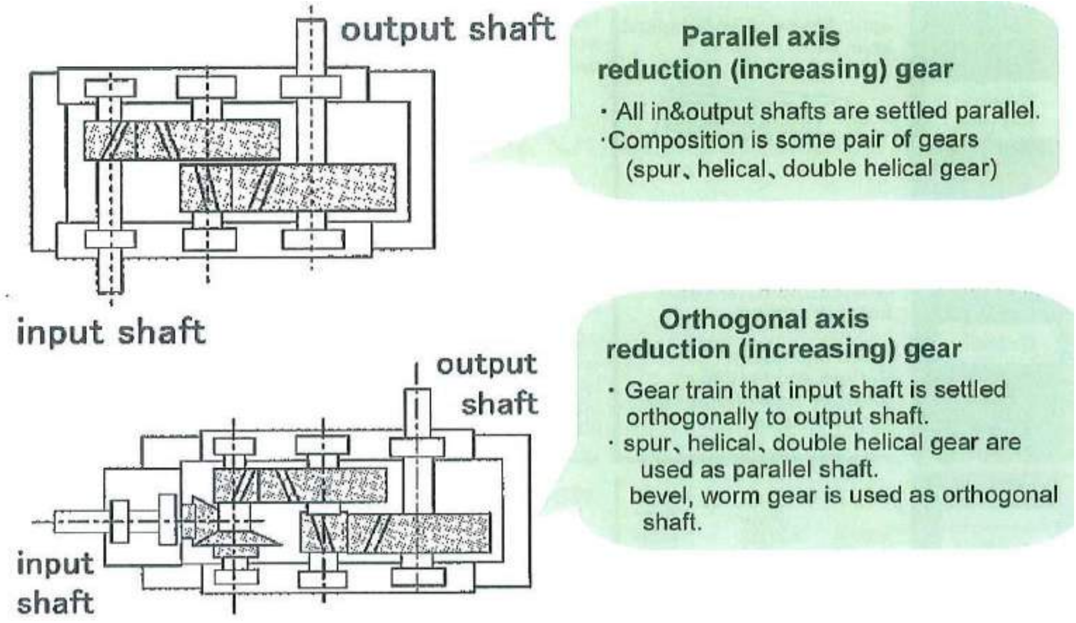
### Gearbox lubrication - oil analysis

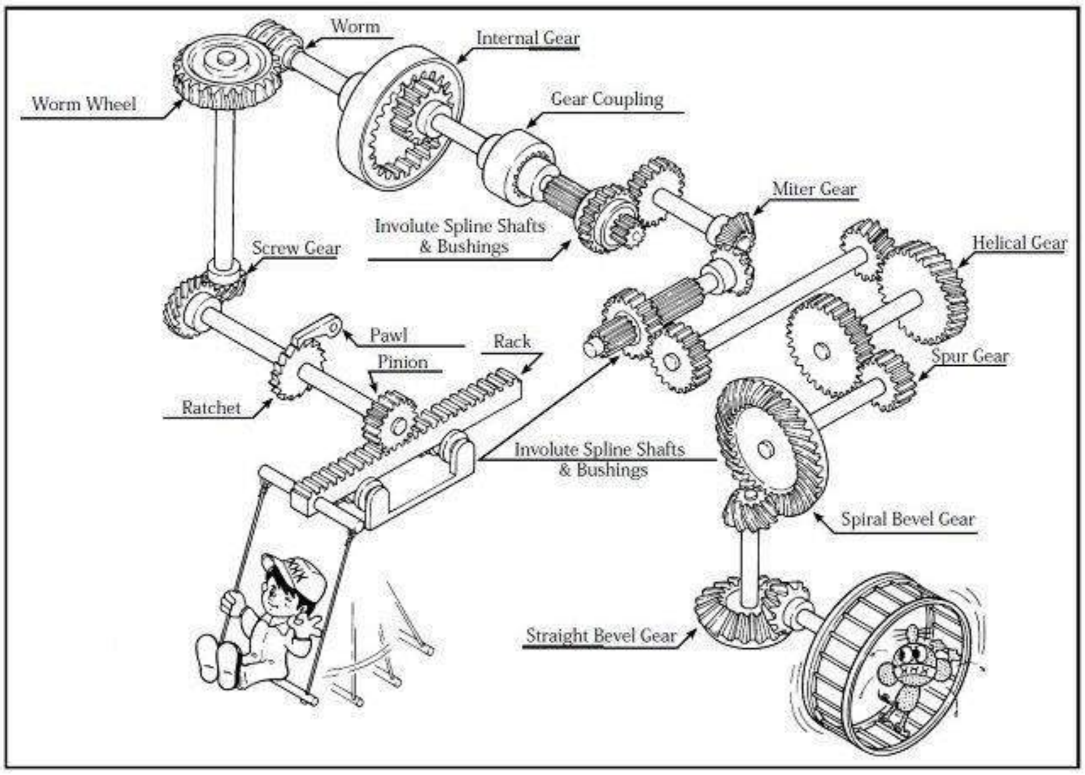
Proper lubrication is extremely important for the lifetime and condition of the gearbox. In many cases, gear and bearing problems result from contaminated or insufficient oil. Oil filter contamination could cause bearing failure and gear tooth damage. Sometimes insufficient lubrication causes metal-to-metal contact with abrasive wear as a result. Oil analysis provides important information on wear modes and possible gearbox lubrication problems. On the other hand, visual inspections of wear patterns and gear tooth pitting can reveal lubrication problems e.g. oil leakage or improper lubricants.

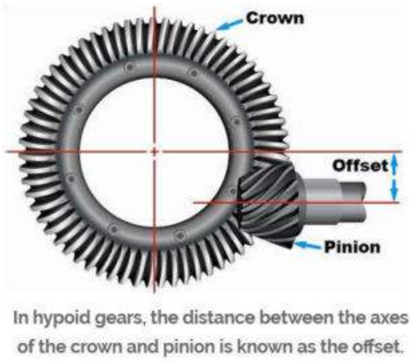
**Vibration analysis:**

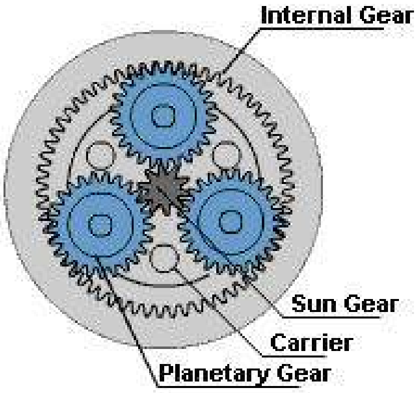
In addition to oil analysis, a vibration analysis is an effective technique for monitoring the condition of the gears and bearings and determines the root cause of machine failure.
on-site vibration measurements detecting various sorts of gearbox problems:

- ✓ gear damage (e.g. scoring, abrasive wear)
- ✓ bearing defects (cage fractures, inner/outer ring damage)
- ✓ alignment errors
- ✓ looseness
- ✓ imbalance
- ✓ resonance areas

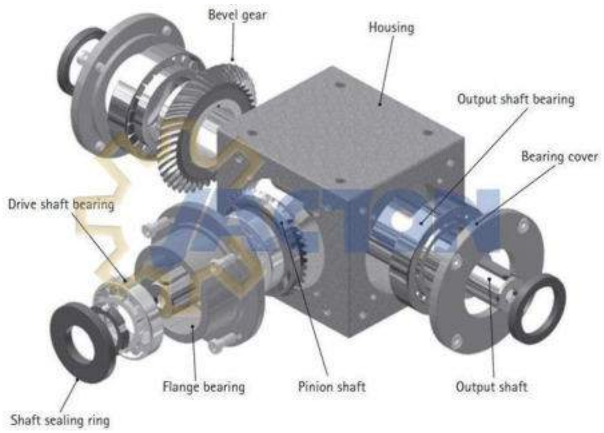

output shaft
Parallel axis reduction (increasing) gear
・All in&output shafts are settled parallel.
・Composition is some pair of gears (spur、helical、double helical gear)
input shaft
output shaft
Orthogonal axis reduction (increasing) gear
・Gear train that input shaft is settled orthogonally to output shaft.
・spur、helical、double helical gear are used as parallel shaft.
bevel, worm gear is used as orthogonal shaft.
input shaft


Worm
Internal Gear
Worm Wheel
Gear Coupling
Miter Gear
Involute Spline Shafts & Bushings
Screw Gear
Helical Gear
Pawl
Rack
Pinion
Spur Gear
Ratchet
Involute Spline Shafts & Bushings
Spiral Bevel Gear
Straight Bevel Gear


Crown
Offset
Pinion
In hypoid gears, the distance between the axes of the crown and pinion is known as the offset.


Internal Gear
Sun Gear
Carrier
Planetary Gear

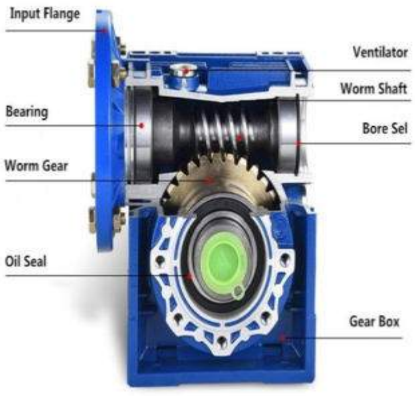
**Hypoid gearbox** **planetary gearbox**



**Spiral bevel gearbox**

**helical gearbox**

**Helical bevel gearbox**



**warm gearbox**

**Gears :**

1) **Bevel Gears**: In these conical shaped gears the teeth perfectly mesh together. These gears are useful when there is a change required in the direction of the shaft's rotation. These gears can be used in different number of teeth to increase or decrease the rotational speed. Although these gears are generally installed on shafts at a 90 angle, they can work well at other angles as well. These gears are also considered very beneficial as they allow adjustments during the assembly stage.

2) **Differential Gears**: This gear is very commonly used in the automobiles. It links two separate shafts with a covering and tunes the total rotational angles of the shafts to that of the covering. These gears are designed in such a manner that when the differential side gear is meshed with the other gear then it produces a high torque, which is transmitted to the axle shaft. There is a set of coaxial gears present in the differential gears. This set includes pinions and turntable.

3) **Girth Gears**: These gears are used in numerous industrial applications. They are unique in the way that unlike other gears, they are made in multiple segments which can be of two, four, or eight equal sizes. Some benefits that one might get by choosing these gears are their low initial cost, ease of installation, simple operation, to name a few. Their most popular standards include AGMA 321.05, AGMA 6004 F88, and ISO 6336. These are also known as split ring gears.

4) **Helical Gears**: These are also one of the well-known types of industrial gears. The involutes teeth of these gears mesh at an angle to create optimum thrust load. The name helical is due to their teeth, which are curved along a helical path or resemble a helix. Their advanced design enables a smooth operation of these gears. Not only this, they can comfortably carry heavy loads due to the enhanced surface contact with teeth.

5) **Spur Gears**: Although these gears are simple in operation, they are used in a multitude of industrial and non-industrial applications. They are often found in cylindrical or disk shapes. These gears are used for the purpose of making variations in the force and speed of rotating axles. They possess straight teeth and are usually installed on parallel shafts. They can be used either separately or in a combination of two or more spur gears, depending upon the scope and nature of the application.

## GEARBOX TESTING

- ✓ Simple spin tests
- ✓ Contact patterns
- ✓ Simulation of actual running conditions and brake loads
- ✓ Bearing temperature monitoring

## For Big gearbox :

## FOUNDATION

The unit must be mounted on a substantial foundation. One system uses a concrete base, a sole plate on the top of the concrete, about 1/8-inch (3mm) shim space, then the gear unit. The sole plate has tapped holes already in place so that bolts can be used to clamp down the feet of the gear unit (with the proper shims in place) at all positions. Once a general elevation is established above the concrete, the sole plate is grouted into place, leaving a space of about a 1/8-inch (3mm) between the top of the sole plate and the bottom of the gear unit feet. This shim space allows room for proper positioning of the gear unit for slow speed and high speed coupling alignment. The most common system in use is a rigid structural steel base plate with the gear mounted with either the driver or driven equipment or the gear and both the driver and driven equipment mounted. The housing must not be twisted or in a bind as this will adversely affect tooth contact and will cause bearing edge loading. Use an adequate area of shims under all tie down bolts. In making up the shim pack, use as few shims as possible so the pack will not be "soft". Check all studs, cap screws and bolts for proper tightening.

## General

Securing proper shaft alignment is one of the most important phases of setting up a gear unit. Any appreciable misalignment can cause a multitude of gear problems from excess bearing and gear tooth wear to vibration problems. Uncorrected misalignment can lead to catastrophic failure. Therefore, it is essential that thermal growth and shaft operating position in the bearings be anticipated during shaft alignment and that good alignment be maintained.

## Anticipation of Shaft Operating Positions

The axial and radial running position of each shaft must be determined and set correctly. The running positions depend on operating load and temperature and will differ from the positions under no load and at ambient temperature because of thermal expansion of the gear housing and the direction of the bearing loading. A temperature rise of 30–70 degrees Fahrenheit (15–40 degrees Celsius) is within normal range. Couplings should allow the shafts to float axially.

The driven and driving machines also have thermal movement which must be either added or subtracted from the gear movement, depending upon the direction of the movements. The gear may be initially centered in the housing by carefully prying the low speed gear through its full axial travel while measuring the distance with an indicator. The gear should be centered when it is positioned at half the full travel amount. The equivalent high speed pinion position is attained when it is torqued into its operating position with the gear still centered.

## Alignment Sequence

The following sequence assumes that the foundation is level, the driving or driven machine (whichever is more permanently settled) is secured, and any shipping locks and covers are removed from the gear unit.

1. Level and secure the gear unit. Jacking screws holes are provided on the base flange for bringing the gear unit to the same horizontal plane as the connecting shaft.

- Shim under the low machine to bring it to the proper height.
- Move one unit until all are in the same plane as the connecting shaft.

2. Establish running position of driven and driving shafts, making sure journals are centered axially and vertically.

3. Connect gear unit shafts and coupling flanges.

- Lubricate the couplings.
- Care should be taken in joining the two coupling halves to observe any coupling match marks.
- Allow for axial thermal growth. Failure to properly align axially can cause cross mesh loading which can lead to premature gear failure.
- Keep outer diameter runout within recommended maximum allowable runout, total Indicator reading (T.I.R.) In a close coupled condition; T.I.R. should not exceed the values.

When Check for free axial movement of the pinion and gear. Do not force shaft movement to the point of damaging the bearing shell.

Tighten foundation bolts.

- Before tightening the foundation bolts, be sure that the base of the gear unit sets evenly on all shims so that there will be no distortion after tightening the bolts.
- After tightening the bolts, check for distortion by placing a dial indicator on the gear housing foot near the bolt to be checked. If the housing foot moves more than 0.002 inch (0.05 mm) when that bolt is loosened, then distortion is present and the housing needs additional shims around that bolt.

Make a soft blue tooth contact check.

## Alignment Checking

When the preliminary soft blue contact check is satisfactory, a hot alignment check should be made by running the gear train until temperatures stabilize, shutting it down and taking indicator readings while the package is hot. If optical alignment equipment is available, the hot alignment check should be made with the package bolted together and running, using the optical alignment flats on the gear unit in conjunction with any optical alignment flats provided on the driving and driven equipment. After complete hot alignment is obtained, the gear unit should be doweled to the foundation or base while the unit is running and temperatures are stabilized. The base flange is drilled for dowel pins, but they must be reamed at assembly. Locate the dowels under both ends of the most critical shaft. (Usually the high speed pinion). Do not use more than two dowel pins and do not put dowel pins on both ends of the unit.

## TOOTH CONTACT CHECK

After completing the alignment and prior to start-up, the tooth contact pattern should be checked. GEAR INSPECTION for instructions on performing a soft blue check and how to interpret results. During testing at the plant, layout blue is applied to the gear teeth so that in the field the contact obtained on the test stand may be verified. The soft blue check after field alignment should match the hard blue contact pattern left on the gears from the Test Stand. After completing the start-up procedure outlined in OPERATION, run the unit for two hours under a light load, shut it down and remove the inspection cover to observe the areas on the pinion where the blue has worn off. If the contact is not satisfactory, the problem is possibly due to gear housing distortion caused by drawing the housing down to a base that is not square with the housing. Be sure the gear housing rests evenly on any shims before tightening the foundation bolts.

## LUBRICATION

At the time of shipment-manufacturer coats interior gear parts with rust preventative oil. This oil should be compatible with the operating oil, and it should not be necessary to flush the unit prior to putting in lubricating oil.

**In the gear drive, lubrication serves three basic functions:**

1. To separate tooth surfaces and prevent metal-to-metal contact, thereby reducing friction and wear.
2. To remove heat losses at the gear mesh.
3. To remove heat produced in the bearings.

It is very important to the successful and satisfactory operation of a gear unit that careful attention be given to proper lubrication, and that the lubricant be kept clean. Every precaution should be taken to prevent water and foreign particles from entering the gear case. If the oil does become contaminated by water or foreign particles, it should be analyzed and changed, if necessary, or cleaned and reconditioned.

## OIL TYPE AND GRADE

The lubricating oil must be high grade, high quality, well refined petroleum oil. Straight mineral type lubricant should be used. Also, it is essential that the oil be clean and non-corrosive to gears and bearings. It must be neutral in reaction, possess good defoaming properties, and also have good resistance to oxidation.

## CHECK BEFORE START-UP

1. Check all electrical, instrumentation and lubrication connections.
2. Check that all necessary piping and accessory wiring is complete.
3. Check the lubricating system for correct type and quantity of oil.
4. Check for correct shaft alignment.
5. Check for foundation bolt tightness.
6. Check tooth contact.
7. Check that coupling , coupling guards and inspection covers are in place.

## START-UP PROCEDURE

The minimum start up temperature for the oil in the gear unit is 70°F (21°C.) It is best to start the unit with an oil temperature as close to operating conditions as possible. Gears starting up with oil temperature below 70°F (21°C) may require additional care to ensure oil is flowing to the mesh and bearings. It may be advisable at low temperatures to slowly start-up or run oil through an auxiliary pumping system (if available) to pre-warm it. Start unit at reduced speed if practical. Monitor bearing and oil temperature as well as oil pressure. Gradually increase speed while continuing to monitor until operating speed is reached.

## CHECK AFTER START-UP

1. Run gear unit at light load while checking for adequate lubrication.
2. Watch the bearings for a sudden high temperature rise which could indicate a bearing problem.
3. Run gear under full load and speed and check for unusual noise and vibration.
4. Also check oil temperature and bearing temperature. After temperature stabilization, the oil temperature into the gear unit should generally not exceed the oil inlet temperature stated on the Installation Plan drawing.
5. After unit has run for two hours under load, shut it down, check any leak , check coupling alignment, check and tighten any bolts that may be loose, and recheck tooth contact.

## Maintenance Schedule Overview

| DAILY | MONTHLY |
|---|---|
| • check oil temperature<br>• check oil pressure<br>• check vibration<br>• check noise<br>• check for oil leaks | • check operation of auxiliary equipment<br>• check operation of alarms<br>• check tightness of foundation bolts<br>• check for oil contamination |
| **QUARTERLY** | **ANNUALLY** |
| • analyze oil sample | • check bearing clearance<br>• check endplay |
| **OIL CHANGE** | • check tooth contact pattern |
| • 2500 hours of operation OR<br>• every six months | • check coupling<br>• check alignment |

## Oil Analysis Guidelines

- **The total acid number increases by 2.** For example: new oil might have a total acid number of 0.4. When this number increases to 2.4 or above, the oil should be changed. This acid number increase is associated with oxidation of the oil which results in oil breakdown.
- **A rapid change in viscosity is noted.** Gear oil is "sheared" as it lubricates the meshing gear teeth. This shearing eventually causes the oil to thin out and lose its film thickness. A rapid decrease could mean oxidation. A decrease of 10% is excessive.
- **The water content is more than 0.1%.** Water in oil causes the oil to lose its film strength and also will cause corrosion to gear elements and bearings.
- **The silicon content is above 50 parts per million.** This signifies the oil is dirty.
- **The iron content is above 200 parts per million.** This indicates contamination from gear

wear particles.

- **A rapid increase is noted in any of the wear elements.** As a guide, if rapid increases of any of the following materials are detected, the probable origins of that material are listed.
  - ✓ **Alloy Steel**–Gear teeth, bearings
  - ✓ **Mild Steel**–Oil pump, slinger, or baffle rubbing gear case
  - ✓ **Cast Iron**–Oil pump
  - ✓ **Aluminum**–Oil seal, seal guards or carriers
  - ✓ **Babbitt** –Journal bearings

## ANNUAL MAINTENANCE

- ✓ Check bearing , clearance and endplay.
- ✓ Check oil sump , breather , sight oil level glass , oil seal , sump body , drain ..etc..
- ✓ Check tooth contact pattern.
- ✓ Visually inspect couplings and check alignment.

## OIL CHANGE INTERVALS

Under normal operating conditions, the lubricating oil should be changed every 2500 hours of operation or every six months, whichever comes first. The unit should be drained by removing the drain plugs Complete oil changes for units with large capacity oil systems are sometimes impractical. In this case, draining the oil system, cleaning the reservoir and/or gear sump, and then recharging the system with the original oil that has been cleaned and reconditioned may be sufficient.

## TOOTH CONTACT CHECKING

### 1 Introduction

The purpose of this guide is to describe why should check gear tooth contact, how the actual check is made, and how to interpret the tooth contact check on power transmission gearing with involute double helical teeth and parallel input and output shafts.

### 2 Why Check Tooth Contact

Gear teeth must have an even load across the entire face width to minimize stress on the teeth. The contact between gear teeth is line contact; therefore, the alignment between the rotating elements (pinion and gear) is critical. Tooth alignment is controlled by the accuracy of the rotating elements, the housing, and the bearings assembly.

### 3 When to Check Tooth Contact

Tooth contact should be checked on all new installations, after any disassembly of the gear unit, and after any major housing-to-foundation change. It may also be checked as part of routine annual maintenance or when a problem related to alignment is suspected. Contact must be checked on the job foundation to be sure the unit will operate properly.

### 4 How to Check Tooth Contact

The contact can be checked two ways.

- ✓ **Soft blue:** Apply soft machinist's bluing or transfer bluing to the teeth of one gear and roll that gear by hand through mesh with its mating gear. (The terms "blue" or "bluing" are used for convenience; the dye is available in other colors.) The transfer of the blue from one gear to the other gear is read as the contact.
- ✓ **Hard blue:** Paint the gear teeth with hard or layout blue, run the gear unit, and observe the pattern of 'wear-off' of the bluing. Contact checking may usually be accomplished through the inspection cover port. Occasionally, soft blue checking is done with the housing cover removed, such as during the reassembly process.

### 5 Soft Blue Method

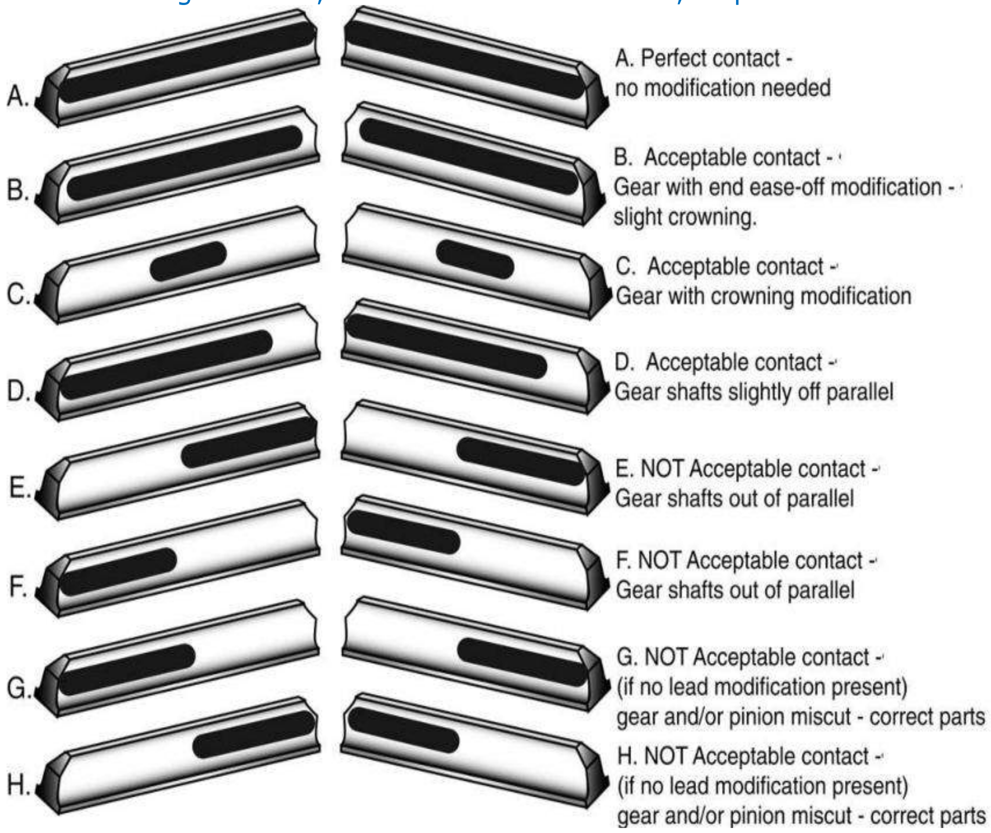
The soft blue method is usually performed first. Since the unit is not running, this check does not give true contact. It does give a good indication of what contact will be. If it indicates inadequate contact, you may choose not to start the unit until contact is corrected. If the unit has been disassembled, then a soft blue check before the housing cover is installed may save a tear-down to correct contact. This is especially important if a new set of rotating elements or bearings is installed. Soft blue is usually applied to three or four teeth on the pinion in two places 180° apart. Clean the teeth thoroughly with solvent, and brush on the blue in a very thin and even layer. With the gear set centered, hold a drag on the gear and roll the pinion through mesh with the gear. Rotation direction is not important, but the contact must be checked on the loaded flank, not the unloaded tooth flank. Observe the blue that transferred from the pinion to the gear. This is the contact pattern. The contact should be checked at three places around the gear (approximately 120° apart;) however, the blue must be reapplied and smoothed on the pinion after each meshing.

### 6 Hard Blue Method

Thoroughly clean the area where hard blue is to be applied. The teeth must be absolutely free of oil, or the blue will not adhere properly and large flakes will chip off, making the contact check inaccurate. Apply the blue to area three or four teeth wide at four places on the gear and at two on the pinion. Run the unit (usually at full speed.) Running conditions may vary from no load to full load. The best way is to run the unit at very light load (up to 20%) for two hours or so, and then shut it down and check the contact. With higher loads the unit should run a shorter time before checking contact. The trick is to run the unit just long enough to wear the blue off the areas of higher contact stress. High loads can mask poor contact and give a false reading.

## INTERPRETATION OF TOOTH CONTACT

The following is information to be used only for guidance in deciding if tooth contact is adequate. Remember that tip or root relief modifications are designed to improve load distribution when a unit is operating under load, but they can make the contact appear quite bad under no load, as in a soft blue check. Generally, with a soft blue check you are looking for some blue to transfer, usually in a line that covers at least 80% of the face width. Do not be alarmed by a lack of blue covering the flank of the tooth; flank contact should normally not extend entirely to the tip of the tooth. See below Figure for examples of tooth contact patterns. Keep in mind that a soft blue contact will not produce such dark impressions–look for the same pattern in a "sketchy" impression. The hard blue check can be done from no load to full load, and the results will vary with the load condition. If the unit is run at no load the test will usually appear similar to a soft blue check. More blue will wear off the pinion than the gear due to the higher number of cycles the pinion sees. As the load increases, blue will wear off more of the tooth flank. Look for evidence of even load across as much of the gear tooth, both flank and face width, as possible.


A.
A. Perfect contact - no modification needed
B.
B. Acceptable contact - Gear with end ease-off modification - slight crowning.
C.
C. Acceptable contact - Gear with crowning modification
D.
D. Acceptable contact - Gear shafts slightly off parallel
E.
E. NOT Acceptable contact - Gear shafts out of parallel
F.
F. NOT Acceptable contact - Gear shafts out of parallel
G.
G. NOT Acceptable contact - (if no lead modification present) gear and/or pinion miscut - correct parts
H.
H. NOT Acceptable contact - (if no lead modification present) gear and/or pinion miscut - correct parts

**Toothed contact pattern**

## GEAR CONDITION ASSESSMENT

During the initial operating period of a set of gears, minor tooth imperfections will be smoothed out, and the working surfaces will polish out under normal operating conditions; however, the life of a gear set may be seriously shortened by the following problems:

- poor coupling alignment
- dirty lube oil
- insufficient lubrication
- poor tooth contact
- overloading the teeth.

In assessing gear wear, **observe carefully and document** the condition of the tooth surface and the operating conditions. It is recommended that before a questionable gear set is considered inoperative, periodic examinations be made with photographs or carbon impressions to determine whether or not the observed condition is progressive.

### Types of Gear Wear or Failure

**Listed below are several common types of gear wear or failure…**

- ✓ Abrasion – Type of wear: Removal or displacement of material due to the presence of hard particles suspended in the lubricant or embedded in the flanks of the mating teeth (includes scoring).
- ✓ Bending fatigue– Progressive failure through crack initiation, propagation, and fracture.
- ✓ Contact fatigue– Cracks and the detachment of material fragments from the gear tooth surface caused by contact stress (includes pitting, spalling and subcase fatigue.)
- ✓ Corrosion– Type of wear: Chemical or electrochemical reaction between the surface of a gear and its environment.
- ✓ Cracks– Splits caused by bending fatigue, mechanical stress, thermal stress, material flaws, or improper processing.
- ✓ Erosion– Type of wear: Loss of material from surface because of relative motion of a high velocity fluid.
- ✓ Fracture– A fatigue failure caused by tooth overloading resulting in gear tooth or portion of tooth breaking off (includes tooth shear.)
- ✓ Plastic deformation– Deformation caused by stress exceeding the yield strength of the material (including indentation, cold flow, hot flow, rolling, tooth hammer, rippling, ridging, burring, root fillet yielding, or tip-to-root interference.)
- ✓ Scuffing– Severe adhesion that causes transfer of metal from one tooth surface to another due to welding and tearing.
- ✓ Wear– Change to a gear tooth surface involving the removal or displacement of material, caused by mechanical, chemical, or electrical action (includes adhesion, abrasion, polishing, corrosion, fretting corrosion, scaling, cavitation, erosion, electrical discharge, and rippling.)

## BEARING CONDITION ASSESSMENT

When the unit is disassembled, the bearings and journal should be carefully inspected for uneven wear or damage. If required, manually polish journals using belt type crocus cloth to remove any high spots.

**Bearing surfaces should be thoroughly inspected for:**

- correct clearance
- high spots
- flaking of babbitt
- scoring
- wiping

### Bearing Clearance

The journal bearings used gears must have clearance between the journal and the bearing. The amount of clearance necessary depends on the oil viscosity, the journal speed and the bearing loading. Each of these parameters is considered in calculating clearance that will provide hydrodynamic lubrication, as well as sufficient oil flow for cooling. Design clearance on the bearings is indicated on the Installation Plan. Measurement of bearing clearances may be accomplished while the gear is stopped by lifting the shaft and measuring the distance traveled with a dial indicator or by using feeler gauges, carefully sliding a feeler gauge between the top of the bearing bore and the shaft. Some wear should be expected, especially on a gear that is stopped and started frequently. The bearing may be considered operational as long as the measured clearance does not exceed the design clearance by more than 0.002" (0.050 mm).

### Bearing Contact and Correction

High speed and low speed bearings should be checked as they are seated for correct bearing contact using Prussian blue dye. This may be done by rolling out one shell at a time for inspection of transfer of blue dye between shaft and journal. To check the bearing contact, install the loaded half of the bearing in each side of the housing with the journal clean and dry. Check the outside diameter of the bearing with a 0.0015" (0.035 mm) feeler gauge to be sure the lower half is seated in the housing. In the axial direction, apply a very light line of Prussian blue to the journal and rotate the shaft 360° by hand. The journal should show blue transfer for a minimum of 80% of the bearing length. After bearing contact is satisfactory, it may be possible to improve gear tooth contact by adjusting the shims under the unit. Do not attempt to modify the bearing contact of a tilt pad journal bearing in any manner except the removal of any localized nicks or dings (high spots). Sometimes gear tooth contact may be corrected by scraping and polishing one of the bearings loaded in the bottom section to spread the contact along the face width. If this is necessary, After correcting bearing and tooth contact and before putting the cover on the gear unit, the bearings should be liberally lubricated with clean oil to provide for initial start-up lubrication.

### Bearing High Spots

Locations of any high spots in the bearing are indicated by bright spots which should be lightly scraped and polished with fine steel wool or crocus cloth until they blend in with the rest of the bearing.

### Flaking of Babbitt

Flaking of babbitt in the load area of the bearing is caused by vibration or shock loading of the bearing material, causing the babbitt to fatigue and break loose from the steel shell. The flakes cause scoring as they pass through the bearing and contaminate the lubricating oil. In the advanced stages of flaking, the load carrying area of the bearing is destroyed and the bearing must be replaced. However, if flaking is caught in the early stages, the bearing may be repaired by scraping and polishing. The cause of vibration or hammering should be corrected before the unit is put back in service.

### Scoring

Scoring, scratching, or marring of the bearing babbitt and/or the journal riding in the bearing is caused by dirt or metal particles in the oil which passes through the bearing. A little scoring is not serious, and the bearing may be polished with fine steel wool to remove any rough edges caused by scoring. Any foreign particles embedded in the babbitt which could score the journal should be carefully picked out, and that area should then be polished smooth. Scoring becomes serious when it significantly reduces the bearing area. In this case, the bearing should be replaced and the gear unit drained and flushed out with a solvent.

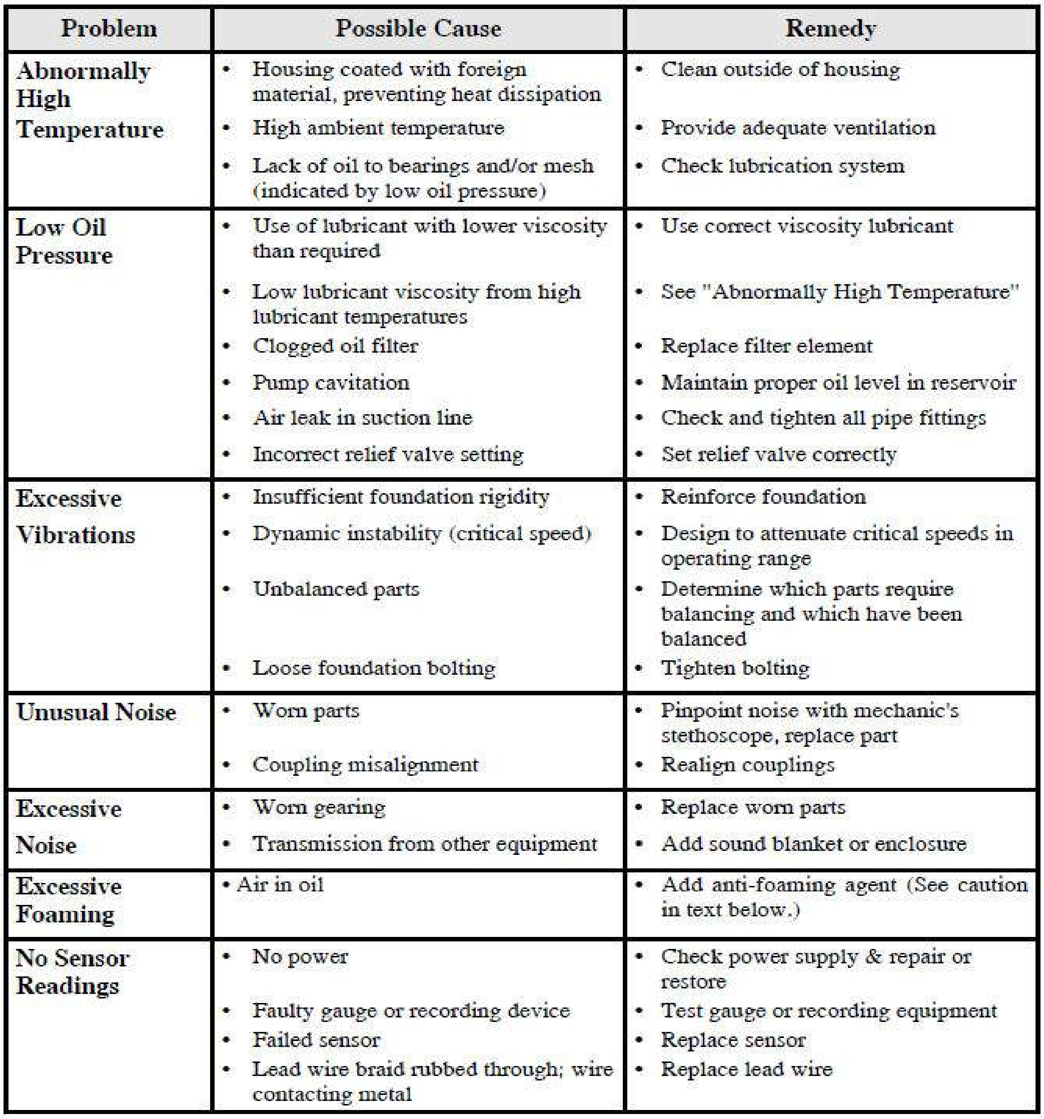
### Wiping

The melting and wiping away of a spot or area of the babbitt is caused by bearing temperatures rising above the pour point of the babbitt. Abnormal bearing temperatures may be caused by:

- insufficient bearing clearances
- insufficient oil pressure
- excessively high oil temperature in the bearing
- a high spot in the bearing
- extreme bearing loading caused by poor bearing contact
- gear mesh failure

If wiping is localized in a small spot, the bearing may be repaired by scraping and polishing the spot until it blends in with the remainder of the bearing; otherwise, the bearing must be replaced. Before replacing a wiped bearing, determine and correct the cause of the wipe.

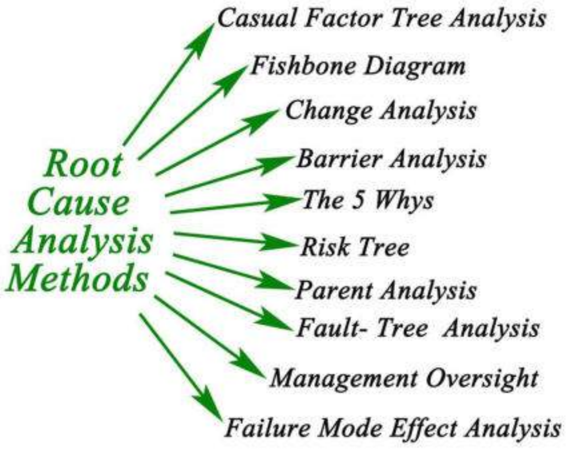
## Trouble shooting chart:

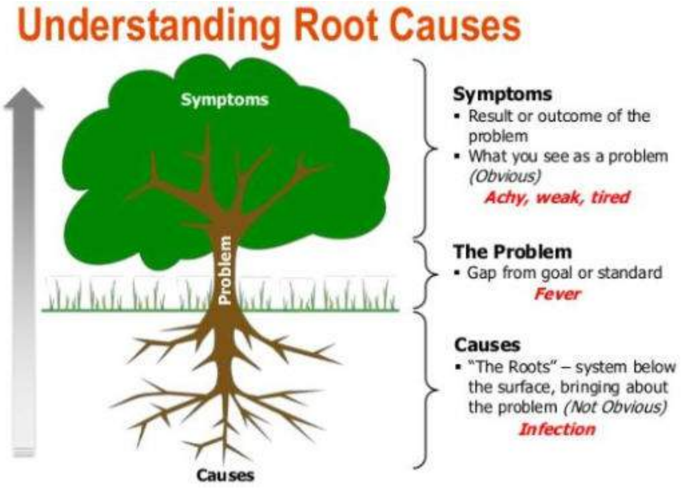


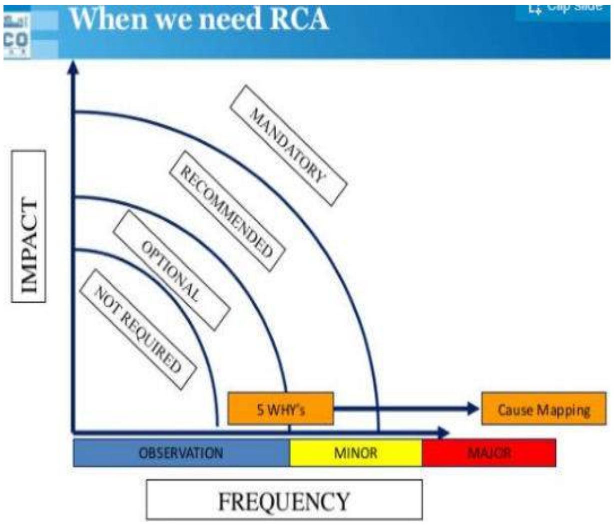
| Problem | Possible Cause | Remedy |
|---|---|---|
| Abnormally High Temperature | • Housing coated with foreign material, preventing heat dissipation<br>• High ambient temperature<br>• Lack of oil to bearings and/or mesh (indicated by low oil pressure) | • Clean outside of housing<br>• Provide adequate ventilation<br>• Check lubrication system |
| Low Oil Pressure | • Use of lubricant with lower viscosity than required<br>• Low lubricant viscosity from high lubricant temperatures<br>• Clogged oil filter<br>• Pump cavitation<br>• Air leak in suction line<br>• Incorrect relief valve setting | • Use correct viscosity lubricant<br>• See "Abnormally High Temperature"<br>• Replace filter element<br>• Maintain proper oil level in reservoir<br>• Check and tighten all pipe fittings<br>• Set relief valve correctly |
| Excessive Vibrations | • Insufficient foundation rigidity<br>• Dynamic instability (critical speed)<br>• Unbalanced parts<br>• Loose foundation bolting | • Reinforce foundation<br>• Design to attenuate critical speeds in operating range<br>• Determine which parts require balancing and which have been balanced<br>• Tighten bolting |
| Unusual Noise | • Worn parts<br>• Coupling misalignment | • Pinpoint noise with mechanic's stethoscope, replace part<br>• Realign couplings |
| Excessive Noise | • Worn gearing<br>• Transmission from other equipment | • Replace worn parts<br>• Add sound blanket or enclosure |
| Excessive Foaming | • Air in oil | • Add anti-foaming agent (See caution in text below.) |
| No Sensor Readings | • No power<br>• Faulty gauge or recording device<br>• Failed sensor<br>• Lead wire braid rubbed through; wire contacting metal | • Check power supply & repair or restore<br>• Test gauge or recording equipment<br>• Replace sensor<br>• Replace lead wire |

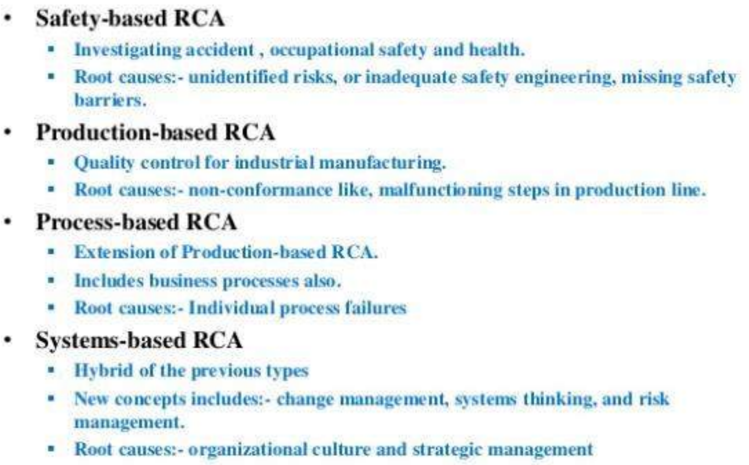
## What is RCA (route cause analysis)

Root cause analysis (RCA) is the process of discovering the root causes of problems in order to identify appropriate solutions. RCA assumes that it is much more effective to systematically prevent and solve for underlying issues rather than just treating ad hoc symptoms and putting out fires.


Root Cause Analysis Methods
Casual Factor Tree Analysis
Fishbone Diagram
Change Analysis
Barrier Analysis
The 5 Whys
Risk Tree
Parent Analysis
Fault- Tree Analysis
Management Oversight
Failure Mode Effect Analysis

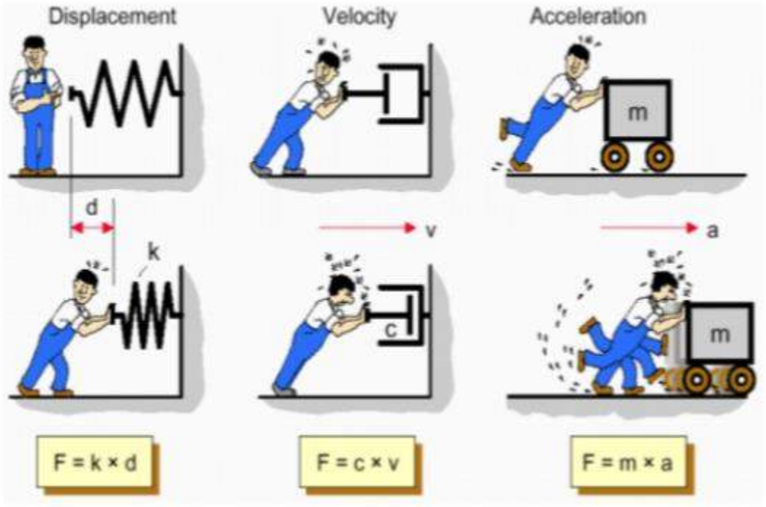

Understanding Root Causes
Symptoms
Problem
Causes
Symptoms
▪ Result or outcome of the problem
▪ What you see as a problem (Obvious)
Achy, weak, tired
The Problem
▪ Gap from goal or standard
Fever
Causes
▪ "The Roots" – system below the surface, bringing about the problem (Not Obvious)
Infection


When we need RCA
IMPACT
MANDATORY
RECOMMENDED
OPTIONAL
NOT REQUIRED
5 WHY's
Cause Mapping
OBSERVATION
MINOR
MAJOR
FREQUENCY



- **Safety-based RCA**
  - Investigating accident , occupational safety and health.
  - Root causes:- unidentified risks, or inadequate safety engineering, missing safety barriers.
- **Production-based RCA**
  - Quality control for industrial manufacturing.
  - Root causes:- non-conformance like, malfunctioning steps in production line.
- **Process-based RCA**
  - Extension of Production-based RCA.
  - Includes business processes also.
  - Root causes:- Individual process failures
- **Systems-based RCA**
  - Hybrid of the previous types
  - New concepts includes:- change management, systems thinking, and risk management.
  - Root causes:- organizational culture and strategic management

## Vibration


Displacement
Velocity
Acceleration
m
d
k
v
a
c
m
F = k × d
F = c × v
F = m × a

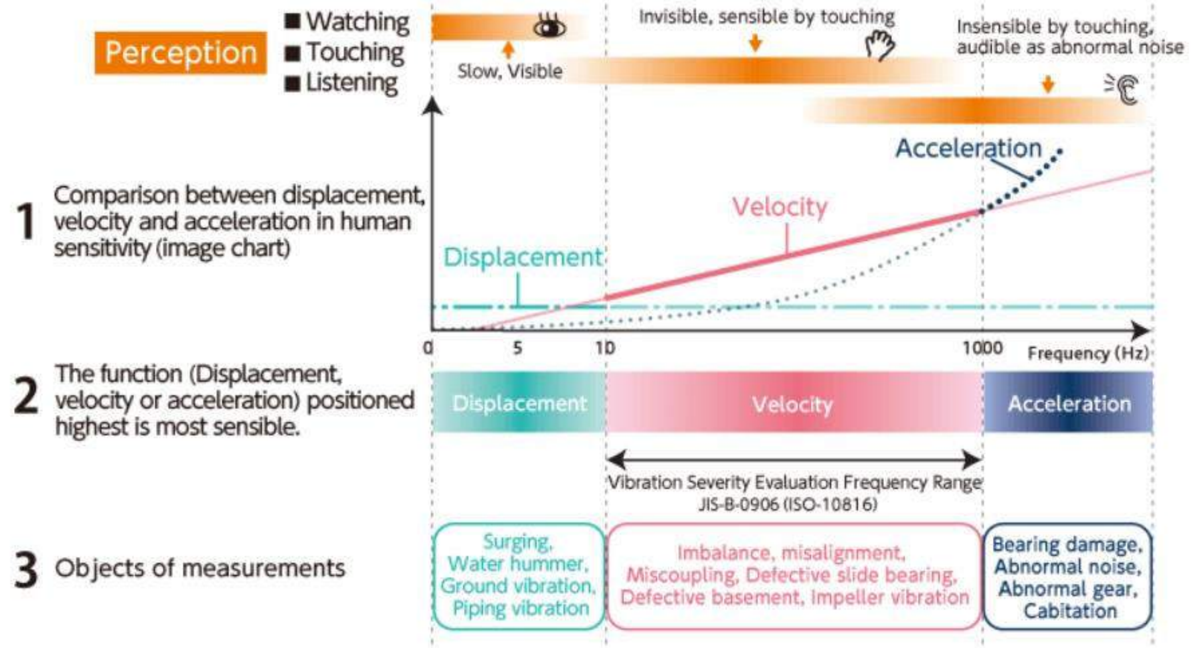
### Definition

Basically, vibration is oscillating motion of a particle or body about a fixed reference point. Such motion may be simple harmonic (sinusoidal) or complex (non-sinusoidal). It can also occur in various modes - such as bending or translational modes , since the vibration can occur in more than one mode simultaneously, its analysis can be difficult.

### Units of vibration

**The units of vibration depend on the vibrational parameter, as follows:**

a) Acceleration measured in g or [m/s2];
b) Velocity measured in [m/s];
c) Displacement measured in [m].


Perception
■ Watching
■ Touching
■ Listening
Slow, Visible
Invisible, sensible by touching
Insensible by touching, audible as abnormal noise
1 Comparison between displacement, velocity and acceleration in human sensitivity (image chart)
Acceleration
Velocity
Displacement
0
5
10
1000
Frequency (Hz)
2 The function (Displacement, velocity or acceleration) positioned highest is most sensible.
Displacement
Velocity
Acceleration
Vibration Severity Evaluation Frequency Range
JIS-B-0906 (ISO-10816)
3 Objects of measurements
Surging, Water hummer, Ground vibration, Piping vibration
Imbalance, misalignment, Miscoupling, Defective slide bearing, Defective basement, Impeller vibration
Bearing damage, Abnormal noise, Abnormal gear, Cabitation

### Vibration Analysis – Basics

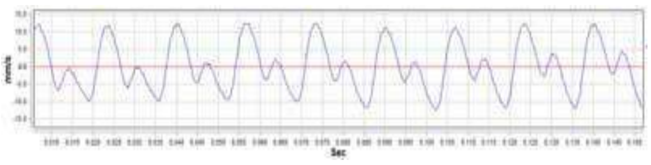
Vibration analysis does not require to disassemble or stop the machine and therefore it **is a non-invasive method**. In fact, a sensor transforming movement into an electric signal is the principle of a vibration analyzer. Secondary, the analyzer calculates all predefined parameters and then stores this signal.

### Vibration Analysis Sensors

The most common **sensor used in vibration analysis is the accelerometer**; however you may also find velocity transducers and displacement probes. In fact, Accelerometers provide a voltage output whose amplitude is proportional to the acceleration of the vibration. Subsequently, the analyzer can integrate this signal to obtain the speed and displacement making the accelerometer the most versatile sensor.

### Concept of Vibration

Rotating machinery produces vibration during its normal operation as a consequence of **friction and centrifugal forces** of both the rotating parts and the bearings. As a result, Vibration can be measured, recorded, trended, and in most cases even heard. Thus, we define vibration as a repetitive movement around a point of equilibrium characterized by its variation in amplitude and frequency. Both the amplitude and the frequency are used in countless essential calculations for diagnosis.



**Time Waveform**

## Characteristics of vibration

**Vibration may be characterized by:**

- **Frequency in Hz**(The hertz (symbol: **Hz**) is the derived unit of **frequency** in the International System of Units (SI) and is defined as cycles per one second. It is named after Heinrich Rudolf Hertz, the first person to provide conclusive proof of the existence of electromagnetic waves.)
- **Amplitude** (in physics, the maximum displacement or distance moved by a point on a vibrating body or wave measured from its equilibrium position. It is equal to one-half the length of the **vibration** path. ) of the measured parameter, which may be displacement, velocity, or acceleration. This is normally referred to as the vibration amplitude when expressed in units, but vibration level when expressed in decibels.

**Decibel notation applied to vibration measurement**

Because of the wide range of vibration amplitudes found in engineering, it is convenient to express the measured amplitude in decibels with reference to a fixed value. Reference values which are internationally accepted are as follows:
a) For velocity, the reference is 10-3 m/s;
b) For acceleration, the reference is 10-5 m/s2.

- **How you can measure the vibration in rotary equipment?**

An accelerometer can be mounted on the surface of the machine which will measure the vibrations acceleration this is usually integrated to velocity for the purposes of analysis. Velocity is usually measured in mm/s (millimeters per second) or IPS (inches per second) while acceleration in usually measured in G (9.8 mm/s/s).

The alternative method is to use proximity probes (which uses an eddy current coil) these will normally be fitted to the machine by the original manufacturer

## VIBRATION ANALYSIS

Vibration is the best tool for assessing the condition/health of a machine. As long as vibrations are normal mechanical condition of a machine is normal.

**Why the vibrations are high? , What is the cause of vibration? , What defect / fault has developed in the machine?**

A method with the help of which the cause of excessive vibration is found out is called as Vibration analysis. In order to analyze the vibrations i.e. to pinpoint the cause of vibration, the analyst has to have knowledge of

**1) HISTORY:** Previous history of vibrations measured on the machine. Failures occurred, maintenance jobs carried out and its relationship with vibration values.

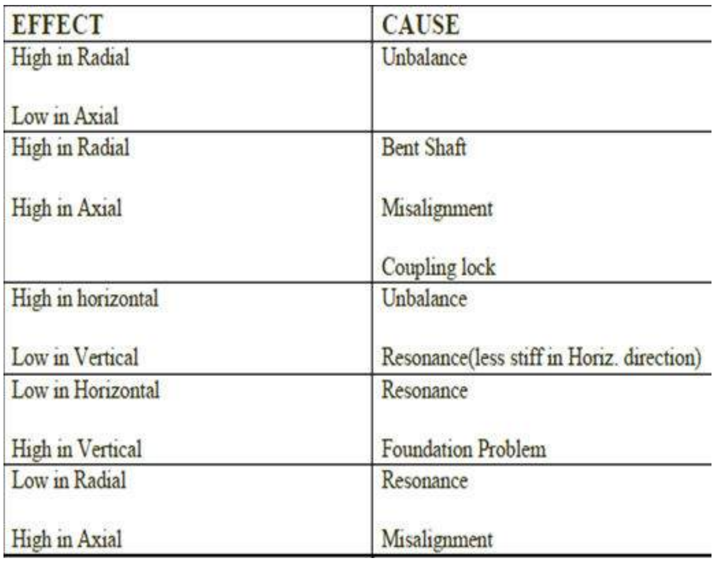
**2) CONSTRUCTION OF M/C:** Constructional and functional details of machine parts. Operating parameters and their interaction with various machine parts. Bearing Clearances, speed, no. of stages, no. of gear teeth, no. of vanes in impeller etc.

### VIBRATION MEASUREMENT AND ANALYSIS TECHNIQUE /BASIC METHOD OF ANALYSIS:

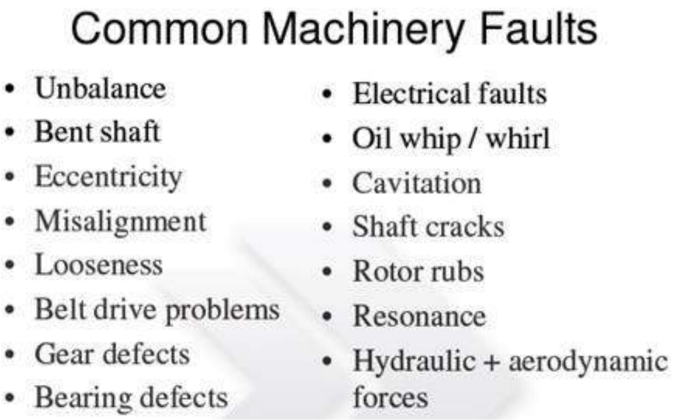
A. OVERALL DATA ANALYSIS
B. SPECTRUM ANALYSIS
C. PHASE ANALYSIS

### A. OVERALL DATA ANALYSIS

Vibrations are normally measured with the help of handy portable vibration meters. These meters give a vibration value which is called as **overall value of vibrations**. It can be in microns (displacement), mm/s (velocity) or in m/s2 (acceleration) **but is always termed as OVERALL reading**. Vibrations are measured in three different directions i.e. Horizontal (H), Vertical (V) and Axial (A). An unwanted force generated by a defect in the machine acts in one or more than one directions. A chart attached herewith shows common defects in the machine and their probable effect on vibrations in different direction.



| EFFECT | CAUSE |
|---|---|
| High in Radial<br>Low in Axial | Unbalance |
| High in Radial<br>High in Axial | Bent Shaft<br>Misalignment<br>Coupling lock |
| High in horizontal<br>Low in Vertical | Unbalance<br>Resonance(less stiff in Horiz. direction) |
| Low in Horizontal<br>High in Vertical | Resonance<br>Foundation Problem |
| Low in Radial<br>High in Axial | Resonance<br>Misalignment |



Common Machinery Faults

- Unbalance
- Bent shaft
- Eccentricity
- Misalignment
- Looseness
- Belt drive problems
- Gear defects
- Bearing defects
- Electrical faults
- Oil whip / whirl
- Cavitation
- Shaft cracks
- Rotor rubs
- Resonance
- Hydraulic + aerodynamic forces

### B. SPECTRUM ANALYSIS

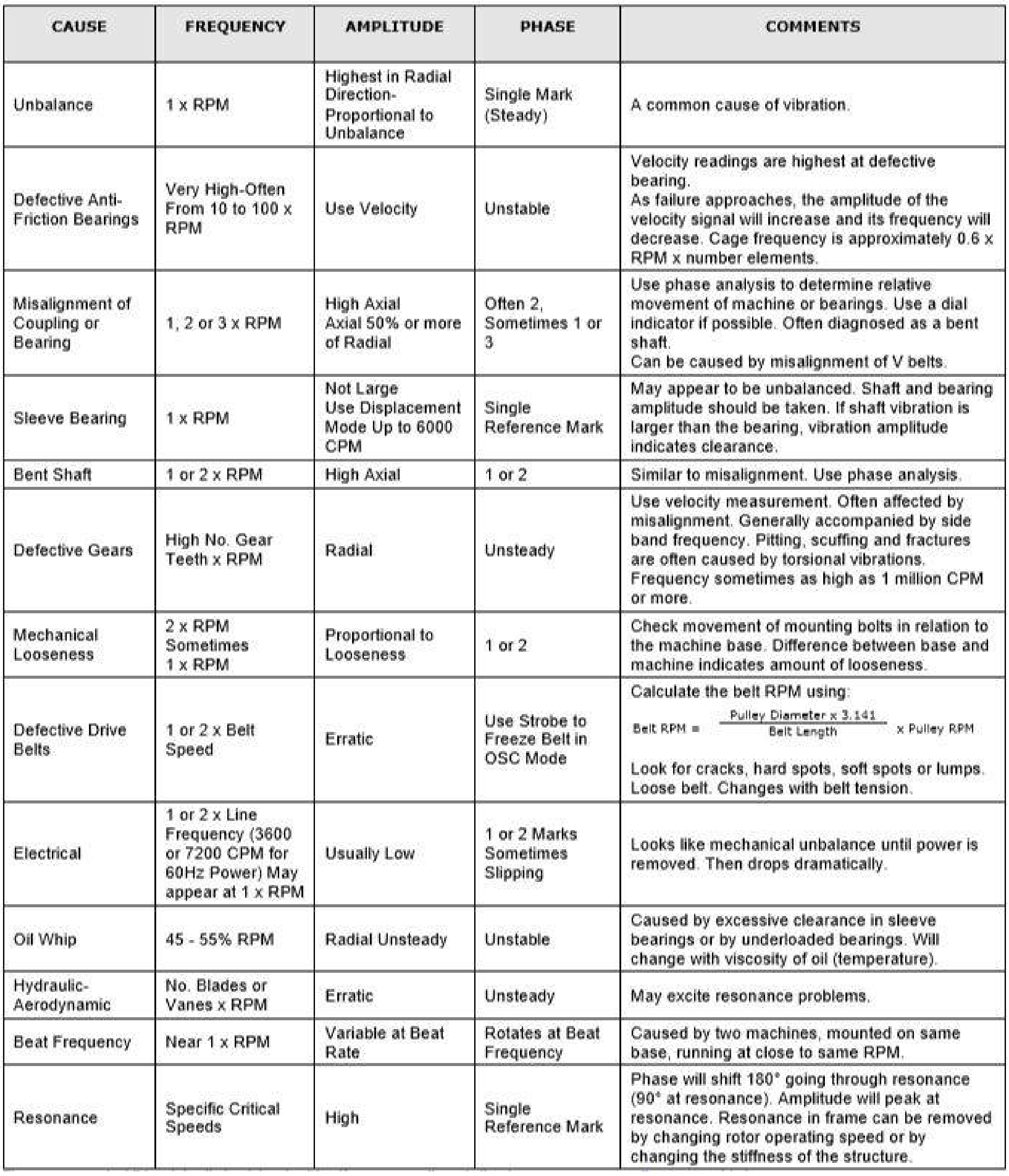
This is a vibration analysis technique wherein the defective component is identified by resolving the vibration signal into its component frequencies and relating these frequencies to the known discrete frequency of the component. A plot showing vibration amplitude on y axis and frequency of x-axis is called spectrum or signature of vibration signal.

**I) Plotting Spectrum Manually:** Some analyzers have a tracking filter which can be used to scan frequency range of vibration. The frequency scanner is manually rotated and the amplitude for each frequency is noted down. An improved version of analyzer scans the selected frequency range automatically and sends signal to the spectrum recorder with pen which plots this spectrum.

**II) Plotting with FFT Analyzers:** Nowadays FFT (Fast Fourier Transforms) analyzers are used for spectrum analysis. In this type of analyzers all the data is collected at one moment and is

i) Either displayed on screen provided with the analyses
ii) Printed on the built in strip recorder or
iii) Offloaded into computer and printed on printer.

After getting the signature of vibration signals each frequency is compared with the Frequency of likely trouble. The chart below gives a guideline for using frequency for identification of faults. The methodology of application of this chart has been dealt with in the subsequent paragraphs.



| CAUSE | FREQUENCY | AMPLITUDE | PHASE | COMMENTS |
|---|---|---|---|---|
| Unbalance | 1 x RPM | Highest in Radial Direction- Proportional to Unbalance | Single Mark (Steady) | A common cause of vibration. |
| Defective Anti-Friction Bearings | Very High-Often From 10 to 100 x RPM | Use Velocity | Unstable | Velocity readings are highest at defective bearing.<br>As failure approaches, the amplitude of the velocity signal will increase and its frequency will decrease. Cage frequency is approximately 0.6 x RPM x number elements. |
| Misalignment of Coupling or Bearing | 1, 2 or 3 x RPM | High Axial Axial 50% or more of Radial | Often 2, Sometimes 1 or 3 | Use phase analysis to determine relative movement of machine or bearings. Use a dial indicator if possible. Often diagnosed as a bent shaft.<br>Can be caused by misalignment of V belts. |
| Sleeve Bearing | 1 x RPM | Not Large Use Displacement Mode Up to 6000 CPM | Single Reference Mark | May appear to be unbalanced. Shaft and bearing amplitude should be taken. If shaft vibration is larger than the bearing, vibration amplitude indicates clearance. |
| Bent Shaft | 1 or 2 x RPM | High Axial | 1 or 2 | Similar to misalignment. Use phase analysis. |
| Defective Gears | High No. Gear Teeth x RPM | Radial | Unsteady | Use velocity measurement. Often affected by misalignment. Generally accompanied by side band frequency. Pitting, scuffing and fractures are often caused by torsional vibrations. Frequency sometimes as high as 1 million CPM or more. |
| Mechanical Looseness | 2 x RPM Sometimes 1 x RPM | Proportional to Looseness | 1 or 2 | Check movement of mounting bolts in relation to the machine base. Difference between base and machine indicates amount of looseness. |
| Defective Drive Belts | 1 or 2 x Belt Speed | Erratic | Use Strobe to Freeze Belt in OSC Mode | Calculate the belt RPM using:<br>$\text{Belt RPM} = \frac{\text{Pulley Diameter} \times 3.141}{\text{Belt Length}} \times \text{Pulley RPM}$<br>Look for cracks, hard spots, soft spots or lumps. Loose belt. Changes with belt tension. |
| Electrical | 1 or 2 x Line Frequency (3600 or 7200 CPM for 60Hz Power) May appear at 1 x RPM | Usually Low | 1 or 2 Marks Sometimes Slipping | Looks like mechanical unbalance until power is removed. Then drops dramatically. |
| Oil Whip | 45 - 55% RPM | Radial Unsteady | Unstable | Caused by excessive clearance in sleeve bearings or by underloaded bearings. Will change with viscosity of oil (temperature). |
| Hydraulic-Aerodynamic | No. Blades or Vanes x RPM | Erratic | Unsteady | May excite resonance problems. |
| Beat Frequency | Near 1 x RPM | Variable at Beat Rate | Rotates at Beat Frequency | Caused by two machines, mounted on same base, running at close to same RPM. |
| Resonance | Specific Critical Speeds | High | Single Reference Mark | Phase will shift 180° going through resonance (90° at resonance). Amplitude will peak at resonance. Resonance in frame can be removed by changing rotor operating speed or by changing the stiffness of the structure. |

## C. PHASE ANALYSIS:

Phase analysis should be used on machine problems when the source of the vibration is not clear or when it is necessary to confirm suspected sources of vibration. A phase study might include points measured only on the machine bearings or can include points over the entire machine from the foundation up to the bearings. Situations in which phase can significantly help with analyzing vibration include looseness/bending/twisting, misalignment, soft foot, bent shafts and rotors, cocked bearings, resonance, and imbalance.

Phase is an important characteristic of a vibration wave & can be used to find out the relative position of any point on vibration wave of a machine part with respect to any point on vibration wave of any other component in same machine. This helps us to distinguish between problems giving vibrations of similar nature, e.g. misalignment v/s bent shaft. Phase is independent of amplitude.

**1. UNBALANCE** -No machine can be balanced perfectly. If the unbalance is within acceptable range, vibration level of the machine (because of pure unbalance) is low. As the unbalance increases vibration level increases. This increase can easily be detected by spectrum analysis since the vibration exists at a frequency equal to the rotating speed of the machine and is normally indicated as 1 X (i.e. one times the machine speed).

**2. MISALIGNMENT -**When the driving machine and driven machine are in one line, then during operating condition no unwanted reactions are observed at bearings. But when there is deviation from their co-axial position a force is generated acting in radial and axial direction of shafts and bearings. The magnitude of this force depends of the amount of misalignment present. This type of fault exhibit 1 X, 2 X, 3 X ... components of frequency.

**3. MECHANICAL LOOSENESS -**Mechanical looseness is normally predominant in the presence of unbalance or misalignment. It is generally reflected by the presence of 2X frequency component, but higher multiples can also be present.

**4. BENT SHAFT-** Bent shaft acts in two ways. Firstly it acts like unbalance and exhibits 1X frequency component. Secondly it acts like misalignment and exhibits high axial vibration and also 2 X, 3 X frequency components.

**5. ANTIFRICTION BEARINGS**: Vibrations also arise because of flaws in the elements of antifriction bearings. These vibrations are normally encountered in high frequency zone and several frequencies are generated simultaneously. These frequencies could be because of

1. Damage to the ball
2. Damage to the inner race
3. Damage to the outer race

Exact damage to the bearing can be ascertained by locating dominant frequency of vibration in high frequency zone. In practice one is least bothered about the type of bearing defect and hence either spectrum or shock pulse method is used to identify bearing condition.

**6. BAD GEARS -**Mismatching of gear profile gives rise to vibrations. This vibration can be identified With the help of spectrum analysis since it is exhibited at the gear meshing frequency. In a complex gear system number of teeth and speed of each gear must be known for identification of meshing problem with a particular gear set. The meshing frequency is calculated as **No. of teeth X speed of the gear**. A broken tooth in a pair of gears gives rise to 1X frequency component in vibration spectrum.

**7. RUBBING-** When rotating part rubs with stationary part it increases stiffness of the rotating assembly. This further increases natural frequency of the rotor assembly so that it matches with exact submultiples of rotating speed. Normally it exhibits vibration at 0.5 X frequency; 1X frequency component is also seen in case of rubbing.

**8. HYDRODYNAMIC**: Flow induced vibrations occur at **n X** frequency, where 'n' is the number of vanes of the impellers. Cavitation in pumps also induces vibrations in the system. It exhibits frequency components at random in the high frequency zone i.e. between 30 kcpm to 80 kcpm.

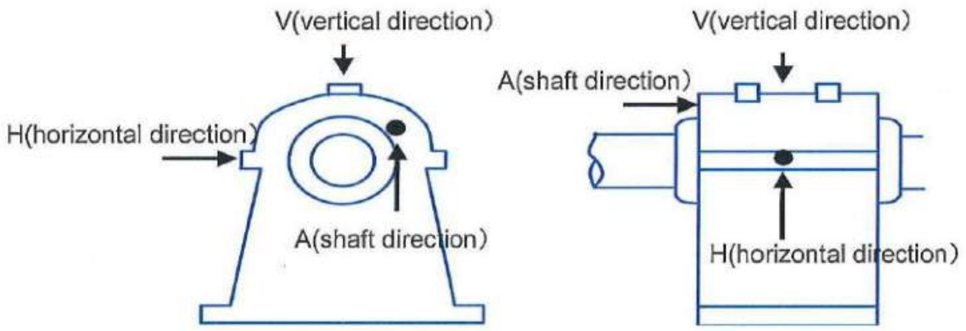
**9. ELECTRICAL FAULTS -** A cause of high vibration of motors can be mechanical or electrical Mechanical fault will exhibit a frequency component according to the fault present. Electrical fault will exhibit vibration at two times the line frequency., i.e. at 6000 cpm(cycle per minute).

**10. RESONANCE -** When the natural frequency of a system matches with the forcing frequency the part vibrate at higher amplitude. This phenomenon is called as resonance.

In rotating machines forcing frequency is rotational speed. But sometimes a force of frequency equal to submultiples (1/2) of multiple (2 X) of rotational speed also induces resonance in the system.

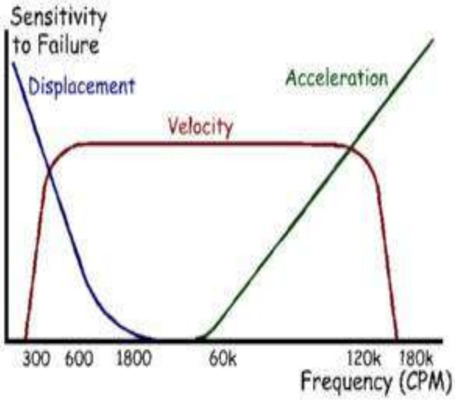
**11. OIL WHIRL/WHIP -** Oil whirl is the unstable state of rotor and the journal bearing. It exhibits vibrations at 0.43 to 0.46 X frequency. This malfunction occurs in high speed rotating machines with journal type bearings.

**To measure selecting point just near bearing and of high strength**



**To measure 3 directions for abnormality by low frequency oscillation, as it has directional tendency by each cause.**
**One direction is enough for high frequency oscillation, as it had no directional tendency.**

**When to use displacement, velocity or acceleration amplitude units in vibration analysis?**

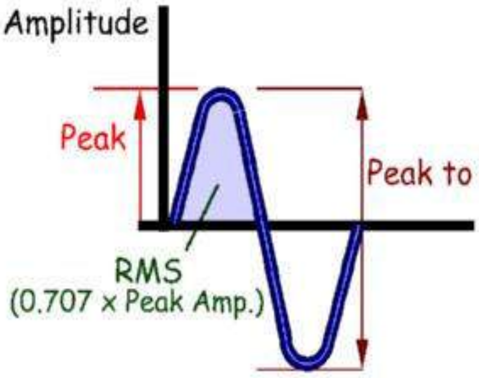


A vibration analyst always has a question whether to use displacement, velocity or acceleration amplitude unit? Here is a rule of thumb based on the frequency.

Displacement is a good measure at lower frequencies especially less than 5 Hz. The failure mode is generally the “stress” causing due to the displacement. Velocity measures how often the displacement is being applied in a given time period. It is related to the fatigue mode of failure. Velocity amplitude unit is a good measure in the range of 5-2000 Hz frequency. Even at small displacement amplitude the repeated motion can cause fatigue failure. Above the 2000 Hz the failure is normally force related. Acceleration is measure of the likelihood of force being the mode of failure.

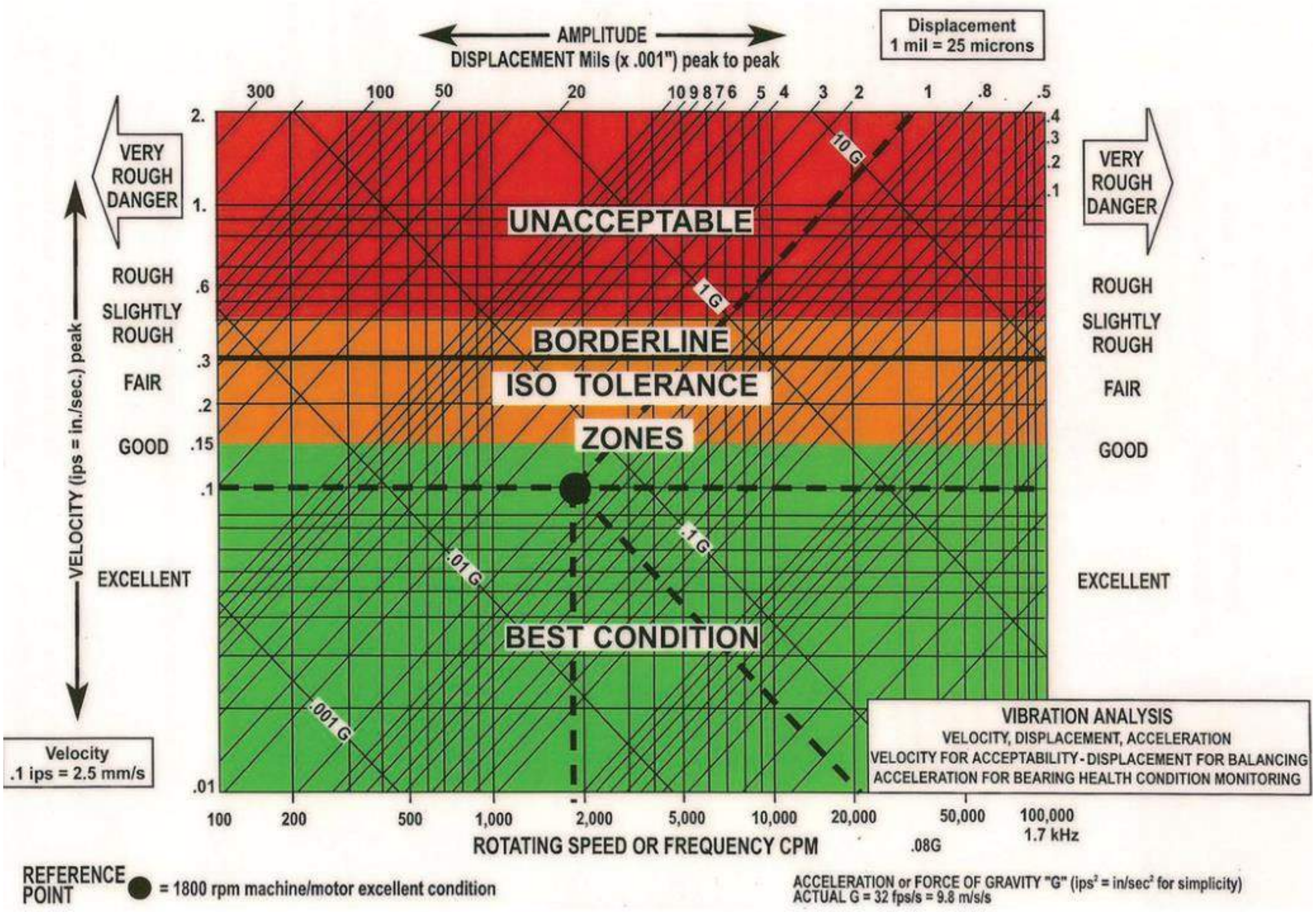
## The Difference Between RMS, Peak and Peak to Peak Amplitudes

The "RMS" ("Root Mean Square")value is calculated by simply multiplying the peak amplitude (shown in the graphic below) by 0.707: RMS = Peak x 0.707

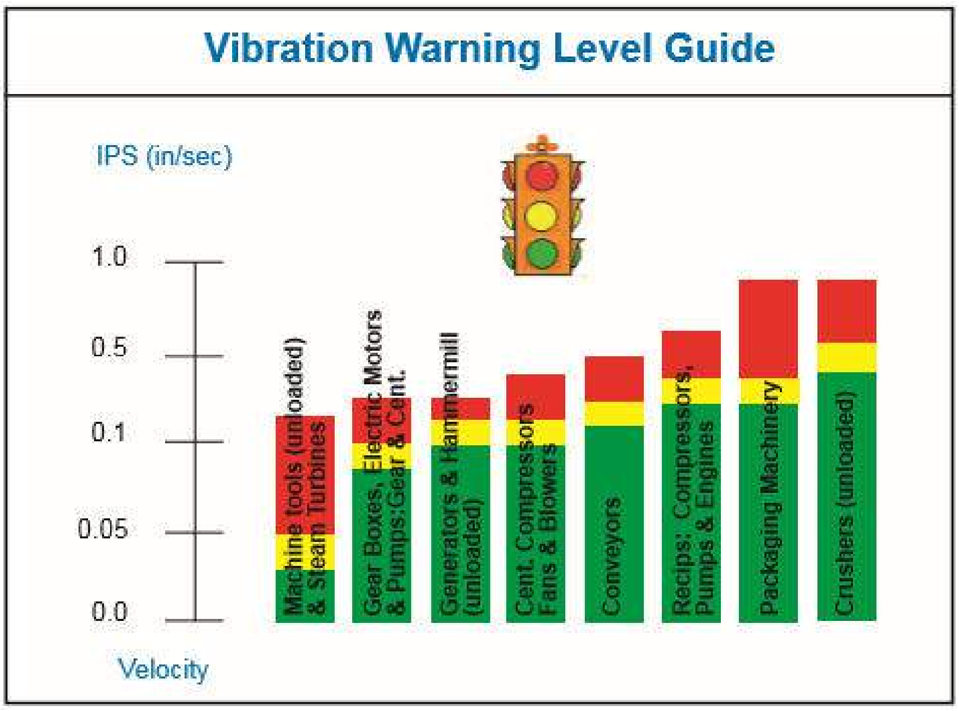


Average Value = 0.637 x Peak Value
RMS Value = 0.707 x Peak Value
Peak Value = 1.414 x RMS Value
Peak to Peak Value = 2 x Peak Value
Peak to Peak Value = 2.828 x RMS Value

### ISO 10816 Vibration Severity Standards:

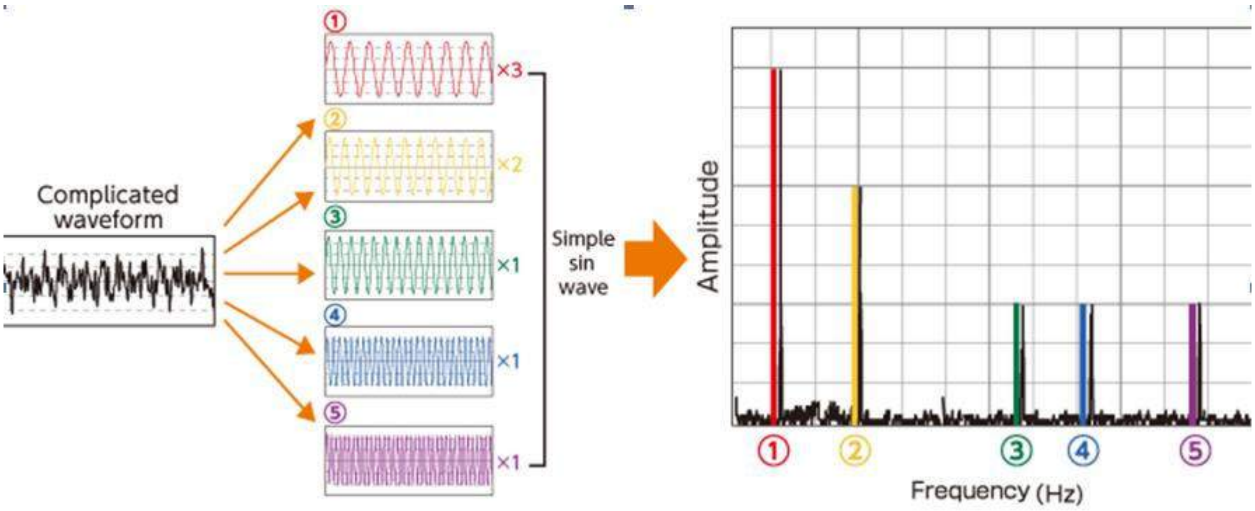


Vibration Severity Graph for General Rotating Machinery



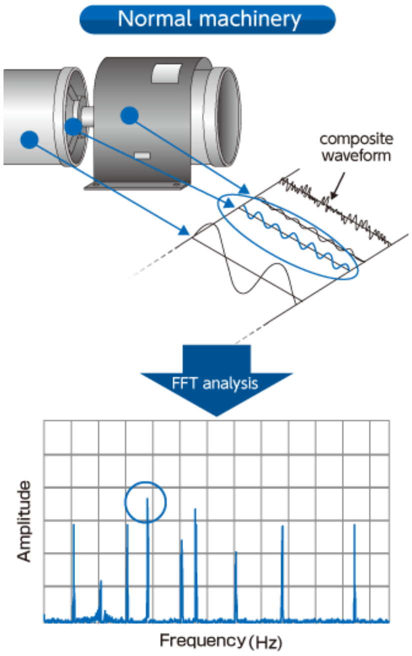
## What is FFT ( Fast Fourier Transform ) ?

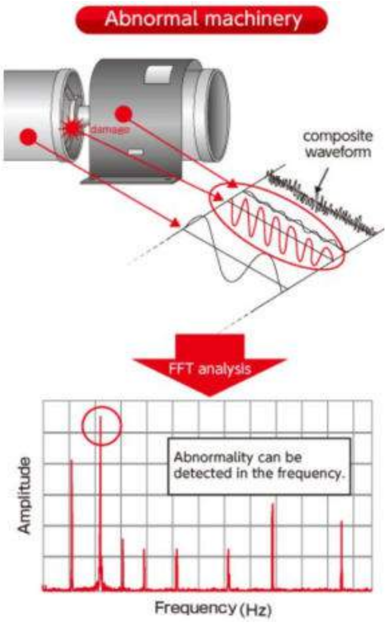
FFT is one method of analysis, based on vibration waveform. waveforms are complicated and difficult to analyze. In FFT, we break waveforms down into a series of discrete sin waves, (left chart） and evaluate each individually. (right chart)


Complicated waveform
①
×3
②
×2
③
×1
④
×1
⑤
×1
Simple sin wave
Amplitude
① ② ③ ④ ⑤
Frequency (Hz)

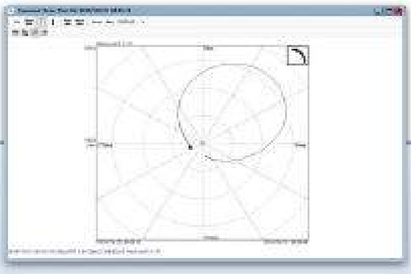
## Making use of FFT spectrum analysis for vibration analysis

When a machine functions abnormally, for example due to imbalance or bearing damage, it will produce different vibrations that can be detected using FFT.


Normal machinery
composite waveform
FFT analysis
Amplitude
Frequency (Hz)

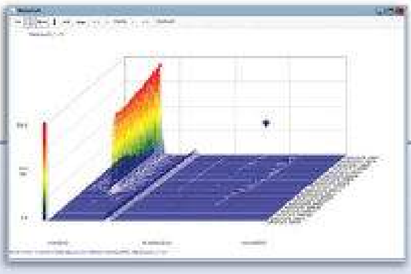

Abnormal machinery
damage
composite waveform
FFT analysis
Abnormality can be detected in the frequency.
Amplitude
Frequency (Hz)

## Different type of Vibration plot to understand issue:



### Polar Plot

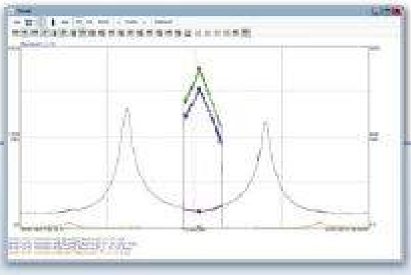
This shows the vibration vector at the time of critical startup/shutdown of the machine. From this plot, the user can observe the balancing condition, vibration levels and critical speed during the startup/shutdown of the machine.
Displayed data (Switchable display): 1X, 2X
This allows over lay of current data on top of past data.



### Waterfall Plot

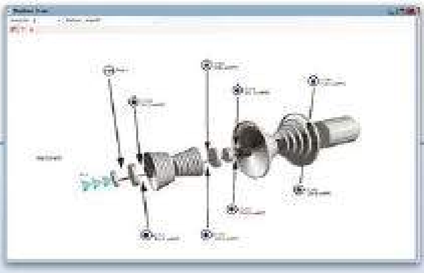
This plot is used to analyze changes in frequency components that occur over time.

Cascade plot can also be displayed with width (z-axis) as rotation speed to analyze changes in frequency components in relation to changes in rotation speed.



### Trend Plot

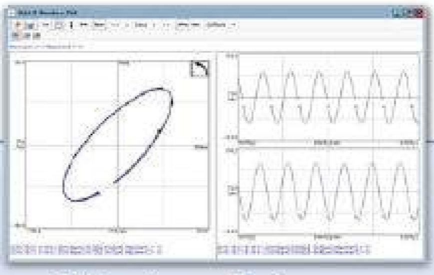
This plot displays short term and long term chronological changes using a line chart.
Displayed data (multiple selections are allowed): Rotation speed, GAP, OA, 0.5 X amplitude, 0.5 X phase, 1X amplitude, 1X phase, 2X amplitude, 2X phase, Not-1X amplitude, nX1 to nX4 amplitude and phase, Smax amplitude, various alarm setting values.



### Machine Train Diagram

The 3D illustration of rotating machinery diagram displays the rotation speed as well as the location and the vibration amplitude of each measuring point.

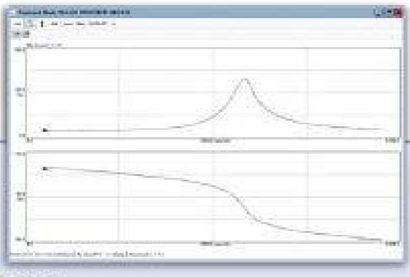
For each machine, current values can be displayed in a list view.



### Orbit and Waveform Plot

This plot composes signals from each X and Y sensor and displays the dynamic motion of the center of a rotating shaft.

The Orbit plot helps to identify any abnormal status including imbalance, misalignment, oil whirl and oil whip.



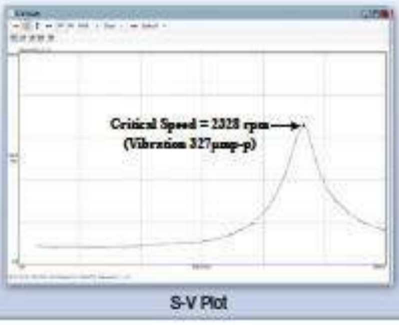
### Bode Plot

This plot displays the amplitude and phase in separate graphs with rotation speed used as the horizontal axis.
From this plot, the user can see the vibration status and critical speed during the startup/shutdown of the machine.
Displayed data (Switchable display): 1X, 2X
This allows over lay of current data on top of past data.

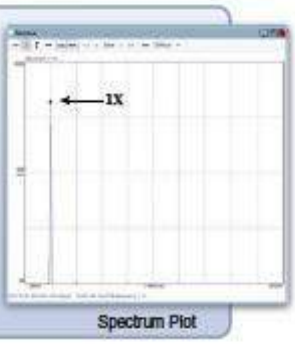
## Unbalanced Vibration

The most common abnormal vibration is due to the mismatch between shaft center and mass center, due to manufacturing error or machine components missing.

The characteristic of the vibration generates the rotation synchronous component (1X), which is sine wave or similar. Vibration becomes largest at critical speed.



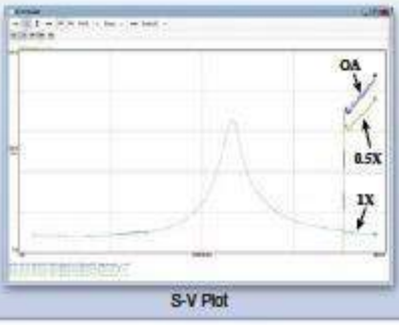
S-V Plot



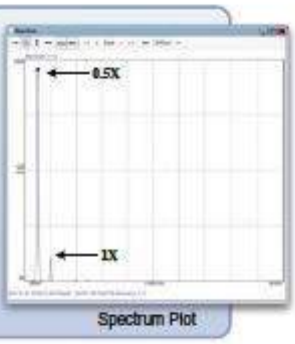
Spectrum Plot

## Oil Whirl Vibration

Self-excited, unstable vibration typical for sleeve bearing supported rotating machinery. Possible causes include effects from the shape of the sleeve bearing, oil film characteristics, etc. Normally, this vibration appears at two or less times lower the critical speed, and the frequency is around half the rotation synchronous frequency (0.5X).



S-V Plot

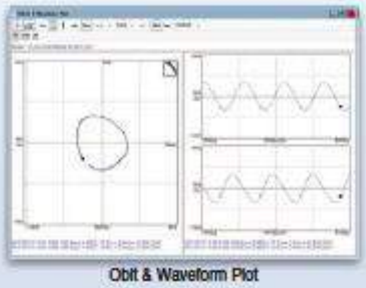


Spectrum Plot

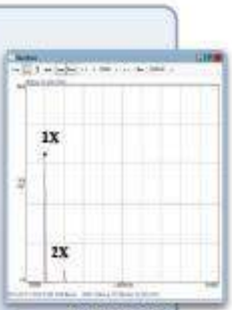
## Misalignment Vibration

Vibration that occurs when the shaft centers of driving rotating machinery and its associated driven rotating machinery are not properly aligned. Typically the vibration includes rotation synchronous frequency component (1X) and harmonic components (2X, 3X).

[Normal condition]

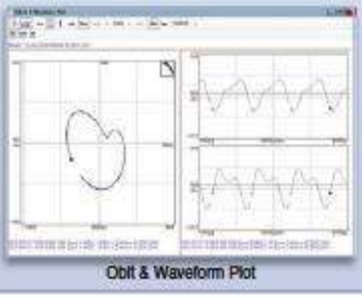


Obit & Waveform Plot

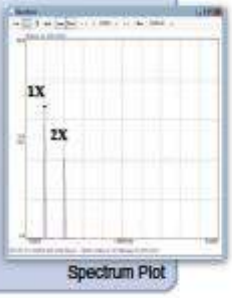


Spectrum Plot

[Misalignment occured]



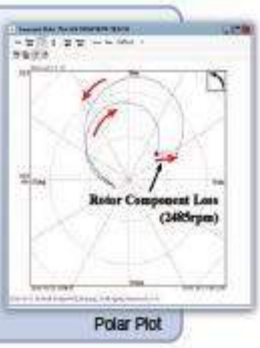
Obit & Waveform Plot



Spectrum Plot

## Loss of Rotor Component

When a piece of rotor component is lost/flies off, unbalanced vibration condition suddenly changes. The typical phenomenon includes sudden changes in the amplitude and phase angle (vibration vector) of the rotation synchronous frequency component (1X).



Polar Plot

**1X:** In a complex vibration signal, the notation for the signal component that occurs at the shaft rotating speed frequency. Also called the **synchronous frequency**.

**2X, 3X, etc.:** In a complex vibration signal, notation for signal components having frequencies equal to exact multiples of shaft rotating speed. Also called the harmonic, super harmonic, & super synchronous frequencies.

**Asynchronous or Nonsynchronous**: A frequency component that is different than shaft rotating speed. Any frequency that is not an integer multiple or fraction of rotating frequency.

**Balancing**: Adjusting the radial mass distribution of a rotor so that the mass centreline (principal inertia axis) approaches the geometric centreline resulting in a reduction in1X lateral vibration.

**Balance Resonance Speed**: A shaft rotating speed (or speed range) equal to a lateral natural frequency of the rotor system. This characteristic is identified when speed changes result in a peak in the 1X vibration amplitude, combined with a change in the 1X vibration phase lag angle. Ideally, a rotor should display a 180° phase change through a resonance, but the measured phase change will generally be less due to nonlinearity, system damping, and/or asymmetry in the system stiffness. Also known as a critical speed of the rotor system

**Blade Passing Frequency**: A potential vibration frequency on any bladed machine (turbine, compressor, fan, propeller, etc.). It equals the number of blades times shaft rotating speed.

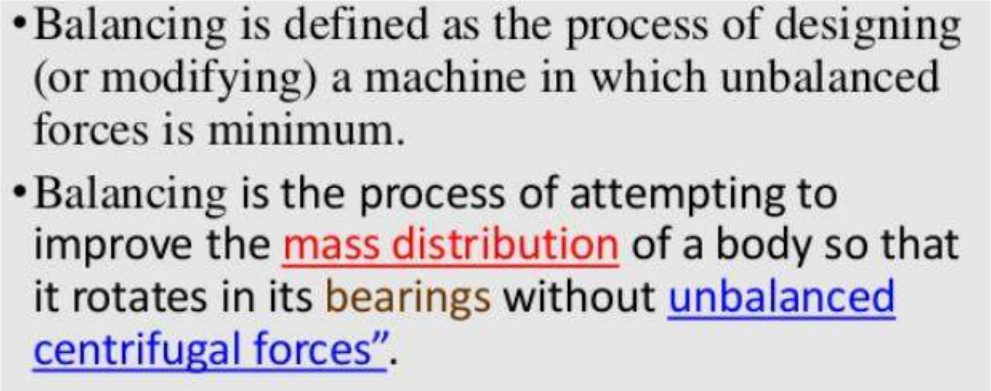
**Unbalance Response**: Vibration amplitude and phase of rotor synchronous precession at a given speed, caused by dynamic forcing action of rotating mass unbalance.
**Vane Passing Frequency**: A vibration frequency on compressors, pumps, and other machines with vane rotating impellers. It is computed by the number of vanes times shaft rotating speed.
**Accelerometer**: An accelerometer is an inertial transducer that converts the acceleration characteristics of mechanical vibration into a proportional electric signal.
**Amplitude & Phase versus Time (APHT) Plot**: An acronym used to describe the trend plot of filtered vibration amplitude & phase lag angle data. This data may be presented in both Cartesian & polar formats for 1X, 2X & nX vibration data.
**Amplitude**: The magnitude of periodic dynamic motion (vibration). Amplitude is typically expressed in engineering units of mils, micrometres for displacement, inches per second for velocity, etc. The signal amplitude can be measured in terms of peak-to-peak, zero to peak, root mean square, or average.
**Amplitude, Trend:** Changing amplitude under steady state operating conditions is a good indicator that something has changed about the machine. Step or rapid changes in amplitude may indicate a serious machine fault requiring a change in operation condition or possibly machine shutdown.
**Bode Plot**: A pair of Cartesian graphs displaying the 1X vibration vector as a function of shaft rotating speed. The Y-axis of the top graph represents 1X phase lag angle, and the Y-axis of the bottom graph represents 1X amplitude. The common X-axis represents shaft rotating speed. Also called an unbalance response plot, and may be used for 2X, 3X, etc. vibration vectors.
**Probe**: Typically, an eddy current proximity transducer, although often used to describe any measurement transducer.
**Seismic Transducer**: Any vibration transducer that measures the absolute vibration of an object. Accelerometers and velocity transducers measure absolute vibration of housing or structures, and are both referred to as seismic, or inertial, transducers.
**Signature**: Term applied to a documentation of machinery vibration behaviour with frequency spectrums, orbits, and time base plots at a specific point in time and under specific machine operating conditions.
**Spectrum Plot**: An X-Y plot in which the X-axis displays vibration frequency, and the Y-axis represents vibration amplitude.
**Transducer**: A transducer that measures the absolute vibration of machine housings , A device for translating the magnitude of one quantity into another quantity. The second quantity often has units of measure different from the first and serves as the source of a useful signal. Vibration transducers convert mechanical motion into a proportional electronic signal.
**Transient Data**: Data (static or dynamic) acquired under transient machine conditions (e.g. startup and coast down). Typical transient dynamic data presentations include polar, Bode, spectrum cascade or waterfall, and shaft centerline plots.
**Transient Vibration**: The temporarily sustained vibration of a mechanical system. It may consist of forced or free vibration or both. Usually transient vibration is associated with instantaneous changes in machine condition such as speed, load, etc.
**Trend Data**: The periodic storage and display of static or dynamic data for the purpose of observing and documenting changes as a function of time.
**Trend Plot**: A presentation in Cartesian or polar format of a measured variable versus time.
**Full Spectrum**: An enhanced spectrum plot produced by using the time base waveforms from X-Y transducers to calculate the amplitudes of the forward and reverse (backward) frequency components in the signals.
**Phase Lag Angle**: The timing relationship (degrees) between two signals such as a Key phasor pulse and a vibration signal. Also the phase difference between two signals, such as the input force signal and output response signal.
**Polar Plot**: Polar format presentation of the locus of the shaft 1X (or 2X, 3X..) filtered vibration vector from a single channel as a function of shaft rotating speed. The polar plot is usually generated during machine start up or coast down (transient operation).
**Prime Spike:** In the study of rolling element bearings, a frequency range which encompasses, as a minimum, the primary bearing fault frequencies and their harmonics.

## MECHANICAL PERSON MUST HAVE:

- Documents (IOM/manuals, drawings, P&ID, ISO drawing etc..)
- plant equipment’s details in XL sheet for ready reference
- Safety valves , measuring tools & lifting tools details (inspection/calibration plan and cirty)
- Spare parts details (set min / max) , daily consumable’s.
- Maintenance Inspection , PM & OH plan and report
- Lubricants details / consumption
- Plant HSE & Work permit policy
- Budget detail / plan

## BALANCING

- **Balancing –** the purpose of balancing is to avoid unpleasant and dangerous vibration produced by dynamic forces due to revolving and reciprocating parts of equipment's.



- Balancing is defined as the process of designing (or modifying) a machine in which unbalanced forces is minimum.
- Balancing is the process of attempting to improve the mass distribution of a body so that it rotates in its bearings without unbalanced centrifugal forces".

**Causes of unbalance……**

**Manufacturing - Causes**

Many causes are for unbalance condition, including

- ✓ **Material problems** such as density, porosity, voids and blow holes.
- ✓ **Fabrication problems** - castings, eccentric machining and poor assembly.
- ✓ **Distortion problems** such as rotational stresses, aerodynamics and temperature changes.

**Assembly - Causes**

When a well-balanced shaft and a well-balanced rotor are united, the necessary assembly tolerances can permit radial displacement, which will produce an out of balance condition. The addition of keys and keyways adds to the problem. Although an ISO standard does exist for Shaft and Fitment Key Conventions (refer to ISO 8821), some use a full key, some a half key and some no key at all. Thus, when a unit is assembled and the permanent key is added, unbalance will often be the result.

**Installed Machines - Causes**

When a rotor has been in service for some time, various other factors can contribute to the balance condition. These include corrosion; wear, distortion, and deposit build up. Deposits can also break off unevenly, which can lead to severe unbalance.

**Other Causes** the difference between types of rotors.

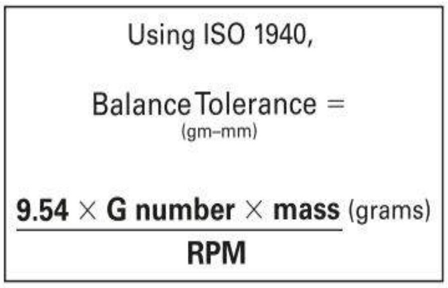
There are two distinct types - rigid and flexible. If a rotor is operating within 70% - 75% of its critical speed (the speed at which resonance occurs, i.e. its natural frequency) it can be considered to be a flexible rotor. If it is operating below that speed it is considered rigid.

**A rigid rotor** can be balanced at the two end planes and will stay in balance when in service.

**A flexible rotor** will require multi-plane balancing. If a rotor is balanced on a low speed balancing machine assuming it is rigid and then in service becomes flexible, then unbalance and thus high vibration will be the result.

**Balance tolerance Standards**

ISO 1940 is famous for its classification of vibration in terms of G codes , it is easy to figure out that G2.5 is a tighter tolerance than G6.3. Notice the choice of words here, tighter not necessarily better. G2.5 means a vibration velocity of 2.5 mm/s under specified conditions. Unfortunately, it is the theoretical value assuming the rotor was spinning in free space so it does not relate to actual operating conditions.



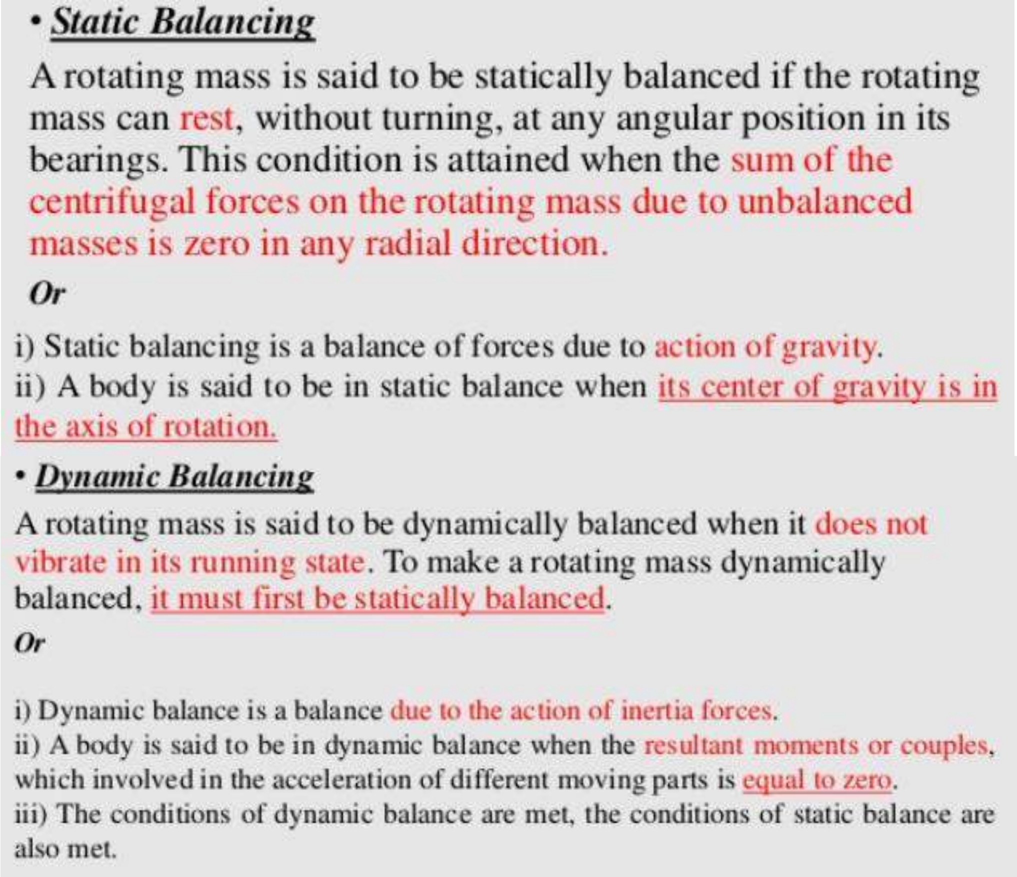
Using ISO 1940,

$$\underset{\text{(gm–mm)}}{\text{Balance Tolerance}} = \frac{9.54 \times \textbf{G number} \times \textbf{mass}}{\textbf{RPM}} \text{(grams)}$$

**BALANCING GRADE**:

- **G 16** --Drive shafts (propeller shafts) with special requirements. Parts of crushing machinery. Parts of agricultural machinery. Slurry or dredge pump impeller. Individual components of engines (gas or diesel) for cars, trucks and locomotives. Crankshaft drives of engines with six or more cylinders under special requirements.
- **G 6.3** --Parts or process plant machines. Fans. Fly wheels. Pump impellers. Machine tool and general machinery parts. Normal electrical armatures. Individual components of engines under special requirements Marine main turbine gears (merchant service).
- **G 2.5** --Gas & steam turbines, including marine main turbines. Rigid turbo-generator rotors. Turbo-compressors. Machine tool drives. Medium and large electrical armatures with special requirements. Small electrical armatures. Turbine driven pumps.
- **G 1** -- Grinding machine drives. Small electrical armatures with special requirements.
- **G 0.4** --Spindles, disks and armatures of precision grinders.

**Static balance** refers to the ability of a stationary on object to its **balance**. This happens when the objects centre of gravity is on the axis of rotation. Whereas **dynamic balance** is the ability of an object to **balance** whilst in motion or when switching between positions.



- ***Static Balancing***

A rotating mass is said to be statically balanced if the rotating mass can rest, without turning, at any angular position in its bearings. This condition is attained when the sum of the centrifugal forces on the rotating mass due to unbalanced masses is zero in any radial direction.

***Or***

i) Static balancing is a balance of forces due to action of gravity.
ii) A body is said to be in static balance when its center of gravity is in the axis of rotation.

- ***Dynamic Balancing***

A rotating mass is said to be dynamically balanced when it does not vibrate in its running state. To make a rotating mass dynamically balanced, it must first be statically balanced.

***Or***

i) Dynamic balance is a balance due to the action of inertia forces.
ii) A body is said to be in dynamic balance when the resultant moments or couples, which involved in the acceleration of different moving parts is equal to zero.
iii) The conditions of dynamic balance are met, the conditions of static balance are also met.

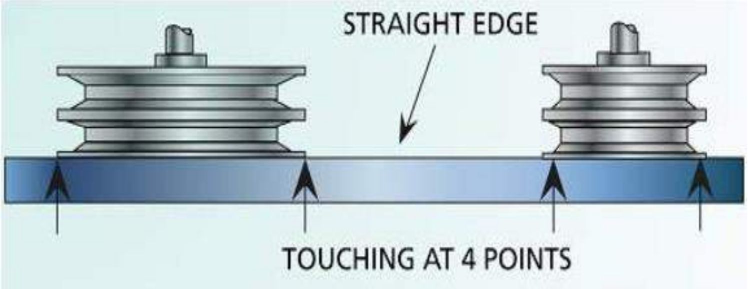
- **BELT / PULLEY ALIGNMENT :**

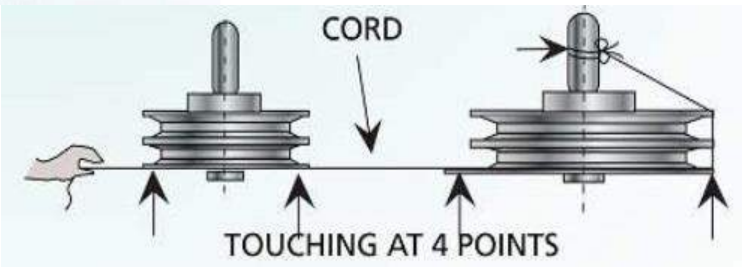
The proper tension of a V-belt drive is the lowest tension at which the belt will not slip at peak-load conditions. For applications without a variable-frequency drive (VFD) or starter, a belt must be tensioned to handle increased motor torque during startup. For slow-start VFD applications, a belt must be tensioned to handle the actual brake horsepower of the fan at the fan shaft.
After initial installation tensioning, retensioning of a V-belt is recommended after one to two days. After that, belt tension should be checked periodically, every six months or more frequently need to be checked , if noise or vibration occurs. Under tensioned belts can slip, generating heat that results in cracking and eventual belt failure. Over tensioned belts stretch excessively, which reduces belt and bearing life, as bearing loads increase. While checking belt tension, one also should inspect for cracks or fraying, as these indicate belt wear.

**There are several methods currently employed to align sheaves (belt /pulley).**

- ✓ "eye-ball" alignment
- ✓ Straight-edge alignment
- ✓ Tight wire alignment
- ✓ Face Mounted Laser System
- ✓ Groove Mounted Laser System

**Eye-Ball** Alignment is when the alignment of the sheaves is evaluated by visual inspection of the belt grooves and possibly the "straightness" of the belt when the tension is adjusted. Obviously there are severe drawbacks to this method. This method depends greatly on the ability of maintenance personnel, distance between the sheaves, quality of the belts, etc. This method is also not very repeatable from operator to operator.
**Straight-edge** - A straight edge is placed on the outer faces of the sheaves. Any deviation in the alignment will present itself as a gap between the sheave face and the straight-edge.





The **Tight-Wire** method is similar to the straight edge. A string, length of dental floss or the like is stretched across the faces of the sheaves. While this method is a lot less expensive than the straight edge, it has the same drawbacks regarding accuracy.

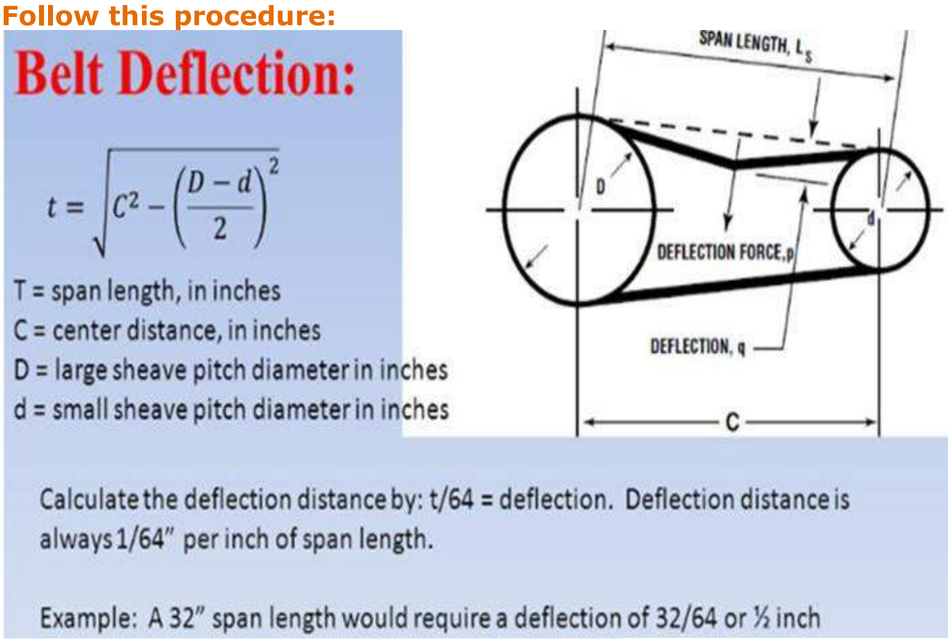
**Laser Based Measurements**

Face mounted laser systems were the first real attempt to address the Vertical Angle or "twist" misalignment as well as the pigeon-toe and offset. This method uses a line laser transmitter magnetically mounted to the face of one of the sheaves.

**GENERAL METHOD :** A few simple rules should be followed to satisfy most drive requirements:

1. For installation, reduce the center distance so the belts may be placed in the sheave grooves without force. Arrange the belts so that both the top and bottom spans have about the same amount of sag. Apply tension to the belts by increasing the center distance until the belts are snug and have a live, springy action when struck with the hand.
2. Operate the drive a few minutes to seat the belts in the sheave grooves. Observe the operation of the drive under its highest load condition (usually starting). A slight bowing of the slack side of the drive indicates adequate tension. If the slack side remains taut during the peak load, the drive is too tight.
3. Check the tension on a new drive several times during the first 24 hours of operation, by observing the slack side span.
4. Keep the drive free of foreign material which might cause slippage or damage to the belt and sheave surfaces.
5. If a V-belt slips, it is too loose. Increase the tension by increasing the center distance. Never apply belt dressing, as this will damage the belt and cause early failure.

**The equipment needed to measure belt tension by deflection are tensiometer, Follow this procedure:**

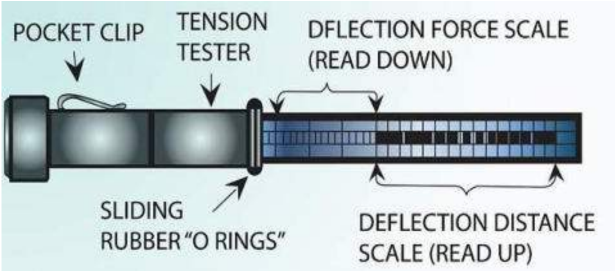

**Belt Deflection:**

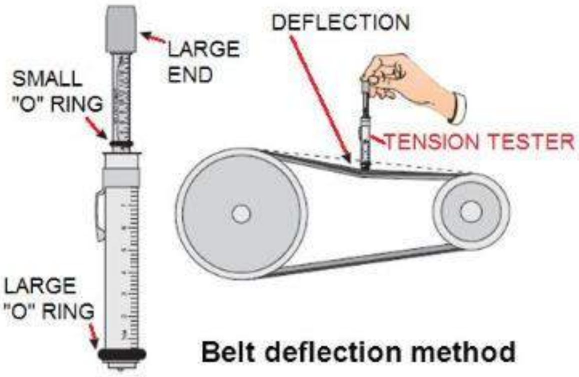
$$t = \sqrt{C^2 - \left(\frac{D-d}{2}\right)^2}$$

T = span length, in inches
C = center distance, in inches
D = large sheave pitch diameter in inches
d = small sheave pitch diameter in inches

Calculate the deflection distance by: t/64 = deflection. Deflection distance is always 1/64" per inch of span length.

Example: A 32" span length would require a deflection of 32/64 or ½ inch


POCKET CLIP
TENSION TESTER
DFLECTION FORCE SCALE (READ DOWN)
SLIDING RUBBER "O RINGS"
DEFLECTION DISTANCE SCALE (READ UP)



Belt deflection method

1. Turn off power to the motor and follow lockout and tagout procedures.
2. Measure the span length of the belt (Figure). Span length is the distance between the sheaves. The desired belt deflection is 1/64 in. for every 1 in. of belt span. For example, if the span length is 32 in., the desired belt deflection is ½ in.
3. Set the large O-ring on the tensiometer to the desired deflection determined in Step 2

4. Set the small O-ring on the tensiometer to the zero mark
5. Hold the tensiometer as indicated in Figure , and press the opposing end of the tensiometer to the midpoint of the belt span, as indicated in Figure . Press down on the tensiometer (deflecting the belt) until the large O-ring is even with the original location of the belt. For a single-belt drive, the tensiometer should be depressed until the large O-ring is lined up with the bottom of the straight edge placed on the outside rims of the two sheaves. For a multiple-belt drive, depress the tensiometer until the large O-ring is even with the top of the next belt.
6. Read the small O-ring, which now indicates the force (in pounds) required to attain the desired belt deflection. Check this reading against the recommended minimum belt-deflection force in Table. For a multiple-belt drive, take a reading from each belt for an average.
7. Tighten or loosen the belt to achieve the recommended minimum belt-deflection force. Tightening the belt will increase belt-deflection force; loosening the belt will decrease it.

**Measuring Belt Tension by Frequency** The natural frequency of a tensioned belt can be used to calculate the tension of the belt. This method is applicable for V- and banded belts.

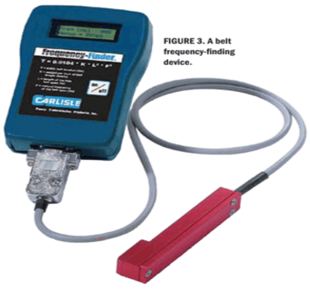
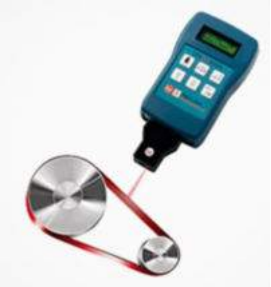


FIGURE 3. A belt frequency-finding device.

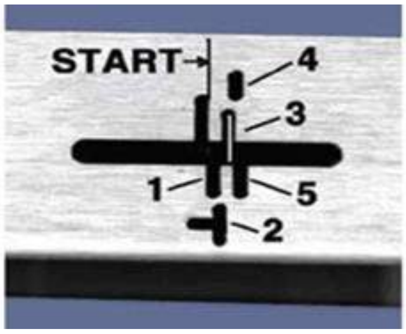


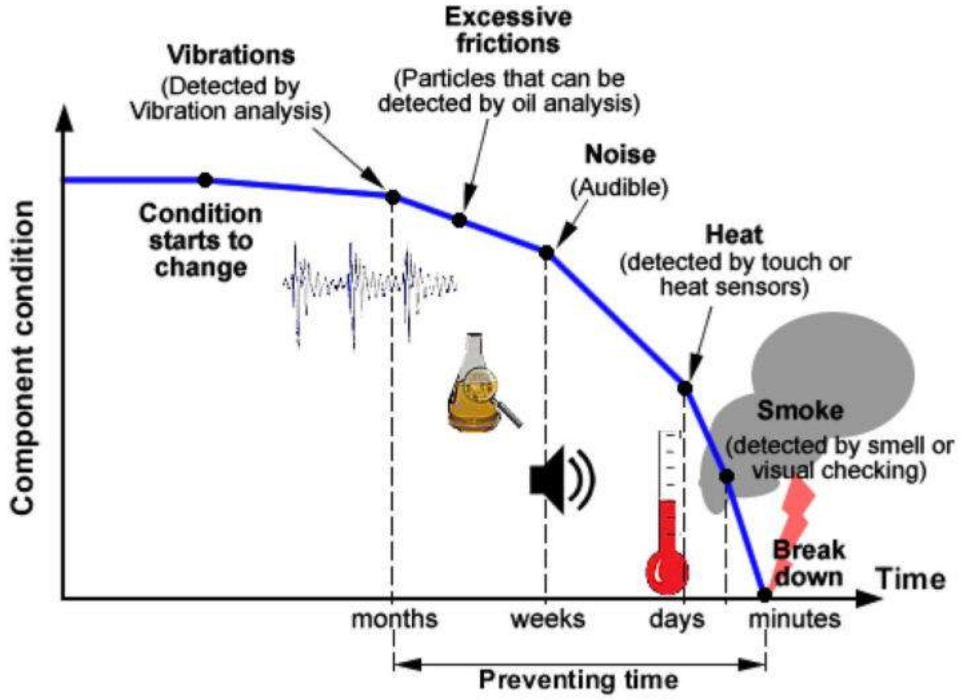
One way to measure the natural frequency of a belt is by using a frequency-finding device (**Figure**). Frequency Finder uses a laser sensor to measure the frequency of a vibrating belt. This frequency then can be compared to the recommended frequency calculated with the software that accompanies the instrument. To measure belt tension by frequency:
1. Turn off power to the motor and follow lockout and tag out procedures
2. Use Frequency Finder's software to calculate the desired minimum and maximum frequency for the belt. The frequency directly correlates with belt tension. The higher the frequency, the greater the belt tension.
3. Turn on Frequency Finder. The laser light will turn on.
4. Tap or pluck the free belt span to induce vibration in the belt.
5. Hold the laser probe no more than 1 in. off the free belt span, with the laser facing the outside of the belt.
6. Check the frequency being displayed (in hertz) on Frequency Finder.
7. Compare the reading from Step 6 to the desired range determined in Step 2. If the reading is below the desired frequency range, tighten the belt. If the reading is above the desired range, loosen the belt.

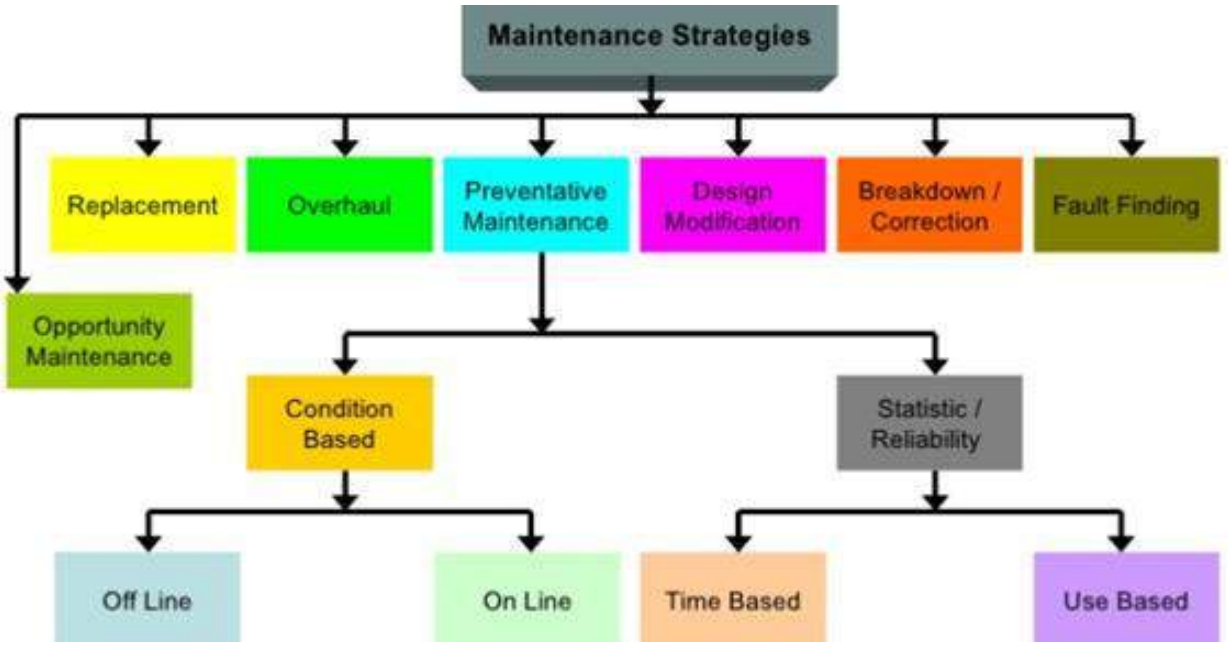
**Using Tension Finder**

Tension Finder is a gauge used to measure the amount of stretch in a tensioned belt. Tension Finder should not be used with aramid or glass-cord belts, as it could result in damage to the equipment.

**To measure belt tension using Tension Finder:**
1. Turn off the power to the motor and follow lockout and tag out procedures.
2. Install the belt loosely on the aligned sheaves.
3. Increase the center distance of the sheaves to apply enough tension to the belts to remove slack.
4. Using a pen or marker, scribe a line on the belt perpendicular to the direction of travel.
5. Place the start slot of the Tension Finder device over the line scribed in Step 4.
6. Attach the spring to the belt with the scribed line still in the start slot of Tension Finder. For reference, if the spring slips, scribe a line on the belt at the spring end of Tension Finder.
7. Determine the required tensioned slot for belt line and belt.
8. Tension the belt until the scribe line from Step 4 is displayed in the designated slot of Tension Finder, as determined in Step 7 (**Figure**).
9. Remove the Tension Finder device from the belt before operation.







**Maintenance Strategies**

- Replacement
- Overhaul
- Preventative Maintenance
  - Condition Based
    - Off Line
    - On Line
  - Statistic / Reliability
    - Time Based
    - Use Based
- Design Modification
- Breakdown / Correction
- Fault Finding
- Opportunity Maintenance

## Corrective / Breakdown

- Repairs made after the equipment has failed and can not perform its normal function anymore
- Justified in small factories where - down times are non-critical : repair costs are less than other type of maintenance : where financial justification for scheduling not felt

## Scheduled

- It is a stitch-in-time procedure and incorporates – inspection, lubrication, repair and overhaul of equipments
- If neglected can result in breakdown
- Eg. overhaul of machines, change heavy equipment oils etc

## Preventative

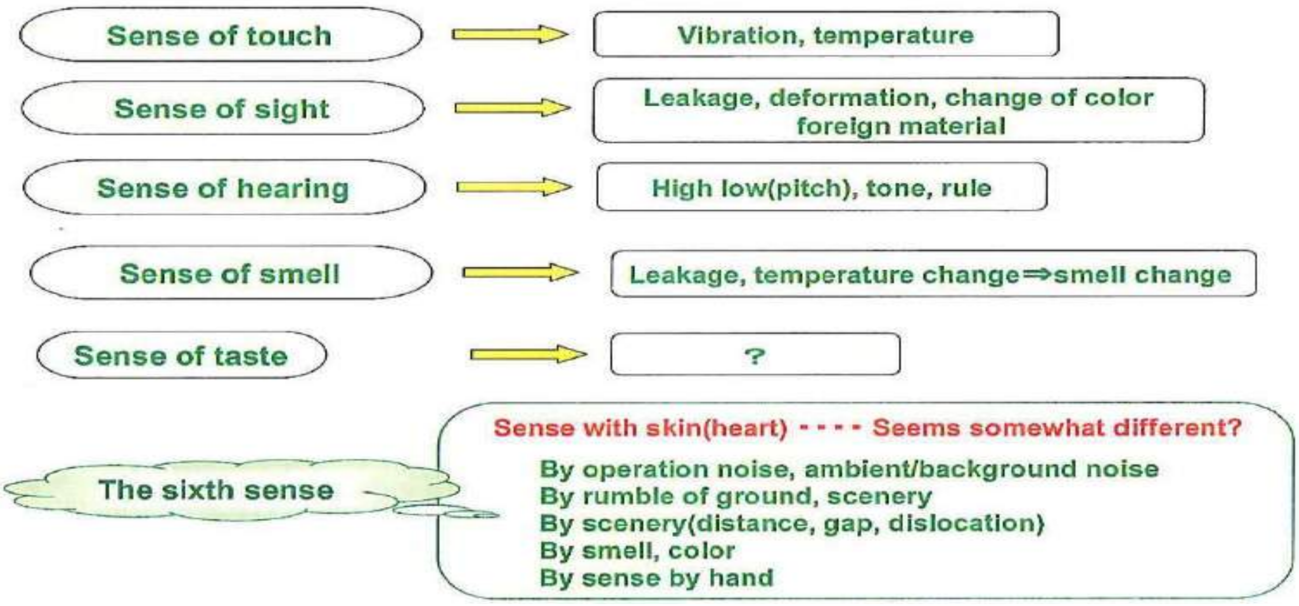
- "Prevention is better than cure"
- Locates weak spots on machinery and equipment
- Provides periodic/ scheduled inspections and minor repairs to reduce the danger of unanticipated breakdowns
- Lower maintenance and repair costs

## Predictive

- Machinery conditions are periodically monitored and this enables the maintenance crews to take timely action - machine adjustment, repair or overhaul
- It makes use of human sense and other sensitive instruments - gauges, vibration analyser, pressure, temperature etc

## Best Maintenance Repair Practices to reduce breakdown

| Maintenance Task | Standard | Required Best Practices | Consequences for not following Best Practices |
|---|---|---|---|
| **Lubricate Bearing** | Lubrication interval – time based ± 10% variance | 1. Clean fittings<br>2. Clean end of grease gun<br>3. Lubricate with proper amount and right type of lubricant.<br>4. Lubricate within variance of frequency | ! Early bearing failure – reduced life by 20-80%. |
| **Coupling Alignment** | Align motor couplings utilizing dial indicator or laser alignment procedures. (Laser is preferred for speed and accuracy) Straight edge method is unacceptable. | 1. Check run out on shafts and couplings.<br>2. Check for soft foot.<br>3. Align angular<br>4. Align horizontal | ! Premature coupling failure.<br>! Premature bearing and seal failure in motor and driven unit.<br>! Excessive energy loss. |
| **V-Belts** | Measure the tension of v-belts through tension and deflection utilizing a belt tension gauge | 1. Identify the proper tension and deflection for the belt.<br>2. Set tension to specifications | ! Premature belt failures through rapid belt wear or total belt failure.<br>! Premature bearing failure of driven and driver unit.<br>! Belt creeping or slipping causing speed variation without excessive noise.<br>! Motor shaft breakage. |
| **Hydraulic components** | Hydraulic fluid must be conditioned to component specifications. | 1. Hydraulic fluid must be input into the hydraulic reservoir utilizing a filter pumping system only.<br>2. Filters must be rated to meet the needs of the component reliability and not equipment manufacturer's specification.<br>3. Filters must be changed on a timed basis on based on filter condition.<br>4. Oil samples must be taken on a set frequency and all particles should be trended in order to understand the condition and wear of the hydraulic unit. | ! Sticking hydraulic<br>! Premature or unknown hydraulic pump life.<br>! Sustaining hydraulic competency by maintenance personnel.<br>! Length of equipment breakdown causes lost production. |



Sense of touch → Vibration, temperature

Sense of sight → Leakage, deformation, change of color foreign material

Sense of hearing → High low(pitch), tone, rule

Sense of smell → Leakage, temperature change⇒smell change

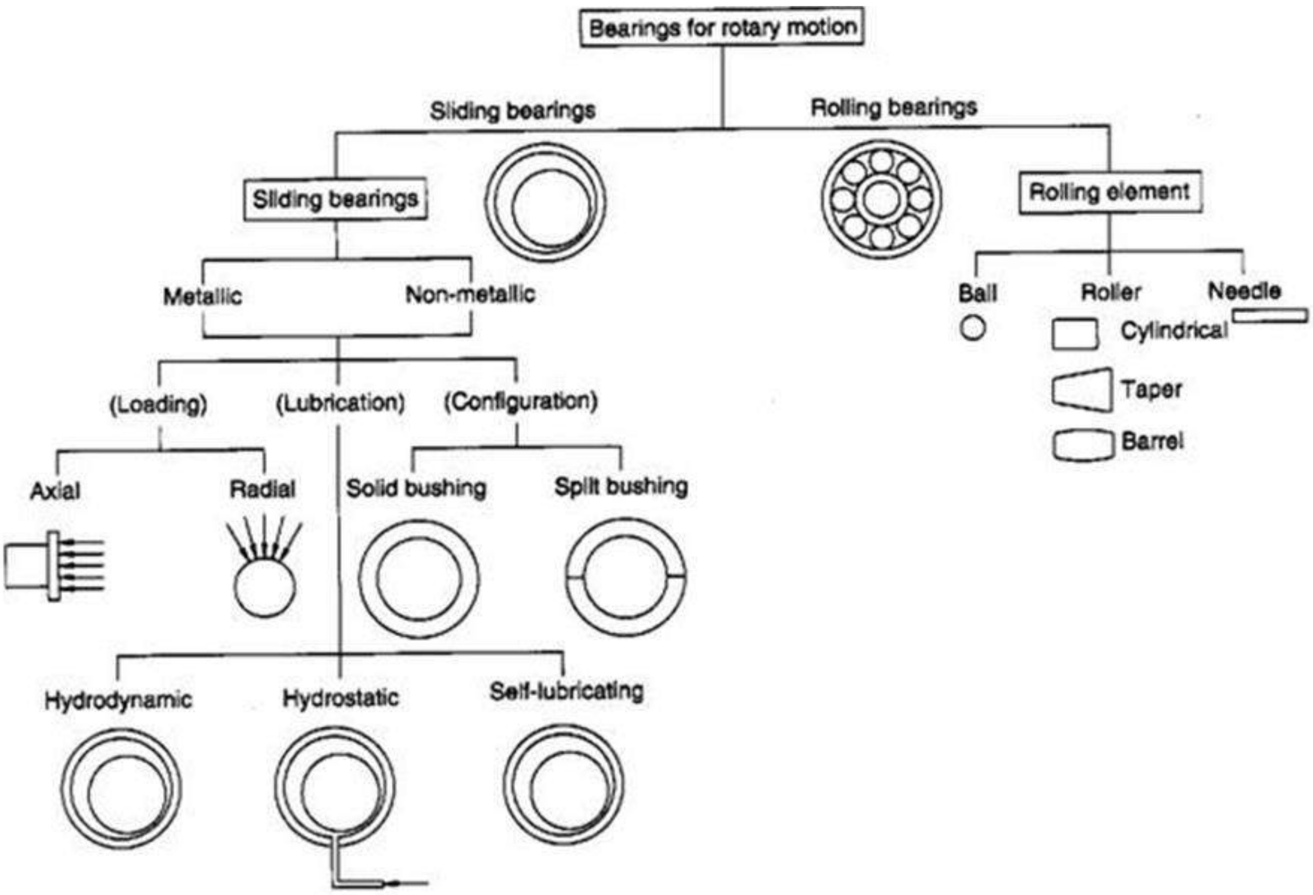
Sense of taste → ?

The sixth sense

Sense with skin(heart) - - - - Seems somewhat different?

By operation noise, ambient/background noise
By rumble of ground, scenery
By scenery(distance, gap, dislocation)
By smell, color
By sense by hand

## Bearing:


Bearings for rotary motion
Sliding bearings
Rolling bearings
Sliding bearings
Rolling element
Metallic
Non-metallic
Ball
Roller
Needle
Cylindrical
Taper
Barrel
(Loading)
(Lubrication)
(Configuration)
Axial
Radial
Solid bushing
Split bushing
Hydrodynamic
Hydrostatic
Self-lubricating

deep groove ball bearing

self-aligning roller bearing

cylindrical roller bearing

self-aligning ball bearing

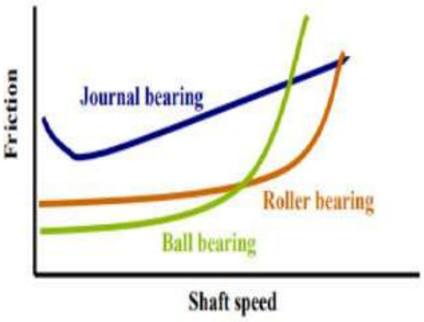
bearing block

tapered roller bearing

thrust bearing

angular contact ball bearing

needle roller bearing



**Bearings:** The **bearing** in its current form was developed towards the end of the 19th century. It was initially made by hand.
Nowadays, bearings are one of the most commonly used machine parts because their rolling motion make almost all movements easier and they help reduce friction.

**Bearings have two key functions:**

- ✓ They transfer **motion**, i.e. they support and guide components which turn relative to one another
- ✓ They transmit **forces**

**Components :**

**Bearings** usually consist of the following components:

- Two **rings** or **discs** with **raceways**
- **Rolling elements** in the form of **rollers** or **balls**
- A **cage** which keeps the rolling elements apart and guides them

**The ABMA (American Bearings Manufacturers Association) provides standards for many bearing types and is affiliated with ABEC (**The **ABEC** scale is an industry accepted **standard** for the tolerances of a ball **bearing**.)**system.**

**ASTM's rolling element bearing standards** provide the **specifications** and test methods pertinent to the design, property, and performance requirements of the mechanical component known as the **rolling element bearing**.

**Ball Bearing** A ball bearing uses a ball to rotate and move the load. Ball bearings are cheaper than other bearings used such as cylinders in roller bearings and have high accuracy. When moving lighter loads ball bearings do not have as much friction as roller bearings, and can support radial and axel loads. Radial loads are perpendicular to the shaft and axel loads are parallel
There are **3 main types of ball bearings**: Deep Groove, Angular Contact and Self- Aligning. The **most common and versatile ball bearing type is the Deep Groove** – it has a groove on the outer face of the inner raceway and a groove in the inner face of the outer.
**Angular Contact Ball Bearings** are similar in design to that of Deep Groove, but they have a shoulder on one side of the inner raceway which determines the precision of the angle – this can be 40, 25 and 15 degrees (Double – Row Angular Contact bearings have a contact angle of 30 degrees). Angular Contact Bearings are normally open but the double – row range is available as a sealed or shielded version.
**Self Aligning Ball bearings** have 2 rows of rolling elements whereby the groove on the outer face of the raceway is similar to that of the Deep Groove ball bearing the inner face of the outer raceway is profiled. It is this that allows the bearing to accommodate mis alignment.

**Roller Bearing** Roller bearings use cylinders instead of balls and usually have a larger diameter. **Roller bearings can support radial loads**, usually of a higher capacity than ball bearings can, but have higher friction with axial loads. Roller bearings are commonly used in rotary appliances and in machinery.
There are **5 types of Roller bearings**: Cylindrical, Needle, Taper, Spherical and CARB (Compact Aligning Roller Bearing – launched by SKF in 1995) Roller bearings tend to be used for medium to heavy duty applications support a substantial weight. The main difference between these and ball bearings is that roller bearings have a larger contact area to that of ball bearings – this means that they can support a heavier load but operate at lower speeds.

**Thrust Ball Bearing** A thrust ball bearing consists of two steel washers with balls situated within them. They are mostly used for low speed appliances and can't handle heavy loads, for example they can be found in swivel bar stools and turn tables.
**Thrust bearings have 3 main variations:** Ball, Roller and Spherical Roller. Their variations are very much alike to that of the comparisons between the ball bearings and roller bearings. Their design is a shaft and axial washer and the central bearing are as separate components. Thrust ball bearings and thrust roller bearings have their own attributes and applications. They are used in low precision applications, but are able to take extreme loadings, but cannot operate at high speeds compared to more standard ball and roller bearings.

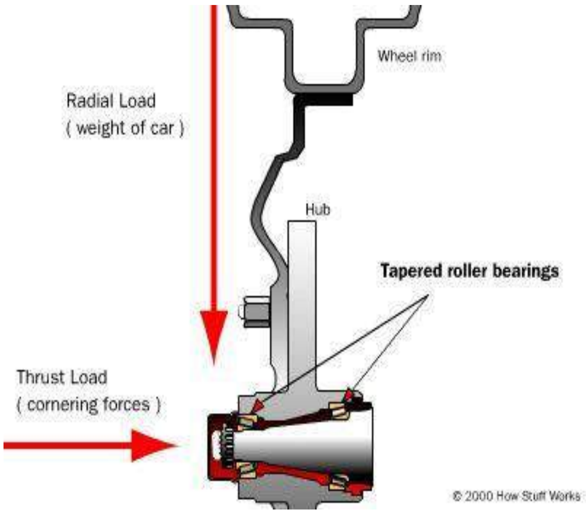
**Roller thrust bearing** Roller thrust bearings can support very large thrust loads. They are often found in gear sets and the rotating shafts. The helical gears used in most transmissions have angled teeth; this can causes a high thrust load that must be supported by this type of bearing.

**Taper Roller Bearing** Tapered roller bearings are used to support large radial and thrust loads. It consists of a series of tapered or conical rollers held in a cage between inner and outer bearing tracks. The disadvantages to taper roller bearings are that they are usually quite expensive and they add more friction than a ball bearing.

**Needle Bearing** Needle bearings are similar to roller bearings but the cylinders are thinner and longer like needles. These are used sometimes as they reduce the friction of the rotating surface.

### How bearings 'bear' load

**Ball bearings are typically capable of dealing with two kinds of loading condition; radial load and thrust load**. Depending on the type of application the bearing is used in, it may experience radial load only, thrust load only or a combination of both. A classic example being the car wheel as shown below.



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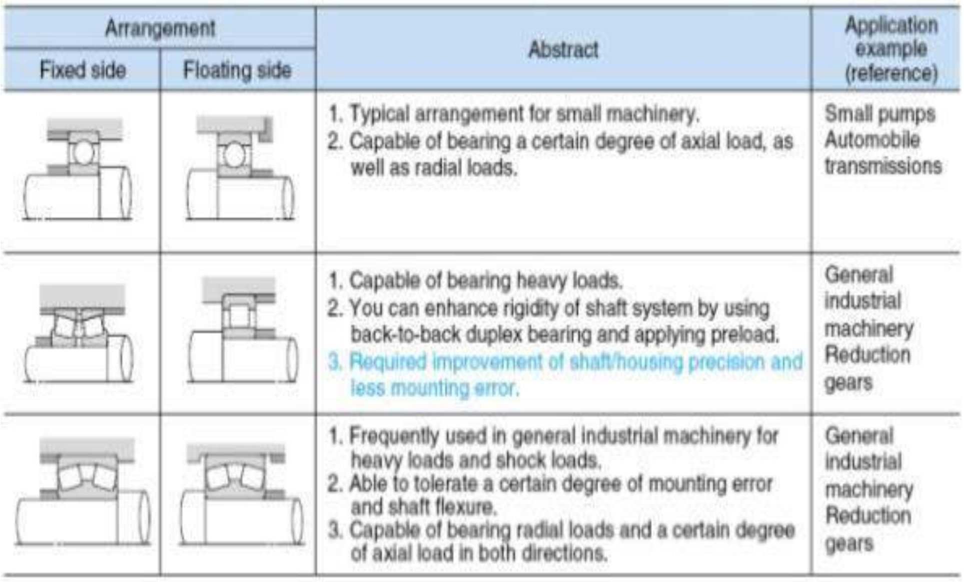
- **What is fixed bearing & floating bearing?**

Shaft assemblies generally require two bearings to support and locate the shaft both radially and axially relative to the stationary housing. These two bearings are called the fixed and floating bearings. **Fixed bearing** takes both radial and axial loads and "locates" the shaft axially in relation to the housing. The **floating bearing** relieves stress caused by expansion and contraction of the shaft and also allows for misalignment caused by fitting errors.

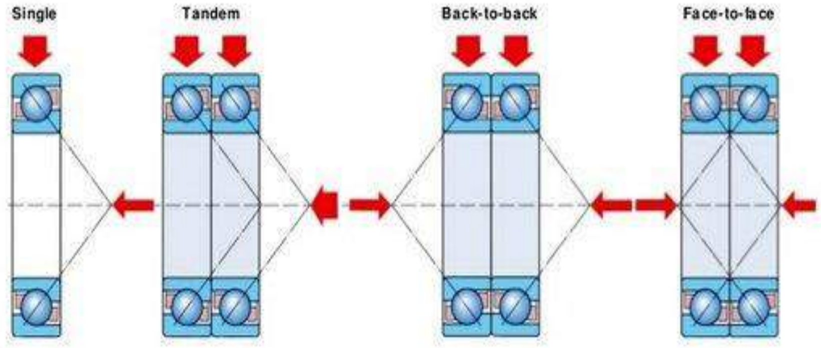
Bearings selection which can support axial loads in both directions are considered most suitable as fixed bearings. In floating bearings the axial displacement can take place in the raceway or along the fitting surfaces. There is also the "cross location" arrangement in which both bearings act as fixing and non-fixing bearings simultaneously. This arrangement is used mainly in comparatively short shaft applications.



| Arrangement | | Abstract | Application example (reference) |
|---|---|---|---|
| Fixed side | Floating side | | |
| | | 1. Typical arrangement for small machinery.<br>2. Capable of bearing a certain degree of axial load, as well as radial loads. | Small pumps<br>Automobile transmissions |
| | | 1. Capable of bearing heavy loads.<br>2. You can enhance rigidity of shaft system by using back-to-back duplex bearing and applying preload.<br>3. Required improvement of shaft/housing precision and less mounting error. | General industrial machinery<br>Reduction gears |
| | | 1. Frequently used in general industrial machinery for heavy loads and shock loads.<br>2. Able to tolerate a certain degree of mounting error and shaft flexure.<br>3. Capable of bearing radial loads and a certain degree of axial load in both directions. | General industrial machinery<br>Reduction gears |

- **What is bearing arrangement?**

Matched bearing sets are matched to each other during production in such a way that when mounting the bearings immediately adjacent to each other, the predetermined values for preload is obtained with even load distribution. The bore and outside diameters are matched to within a maximum of one-third of the diameter tolerance.



**Back-to-back bearing arrangements**

In back-to-back arrangements , the load lines diverge towards the bearing axis. Axial loads acting in both directions can be accommodated, but only by one bearing or bearing set in each direction. Bearings mounted back-to-back provide a relatively stiff bearing arrangement that can also accommodate tilting moments.

**Face-to-face bearing arrangements**

In face-to-face arrangements, the load lines converge towards the bearing axis. Axial loads acting in both directions can be accommodated, but only by one bearing or bearing set in each direction. Face-to-face bearing arrangements are not as stiff as back-to-back arrangements and are less suitable to accommodate tilting moments.

**Tandem bearing arrangements**

In a tandem arrangement , the load lines are parallel so that radial and axial loads are shared equally by the bearings. The bearing set can only accommodate axial loads acting in one direction. If axial loads act in the opposite direction, or if combined loads are present, another bearing adjusted against the tandem arrangement should be added.

- **What is bearing crush?**

Interference between journal bearing to bearing housing is called bearing crush

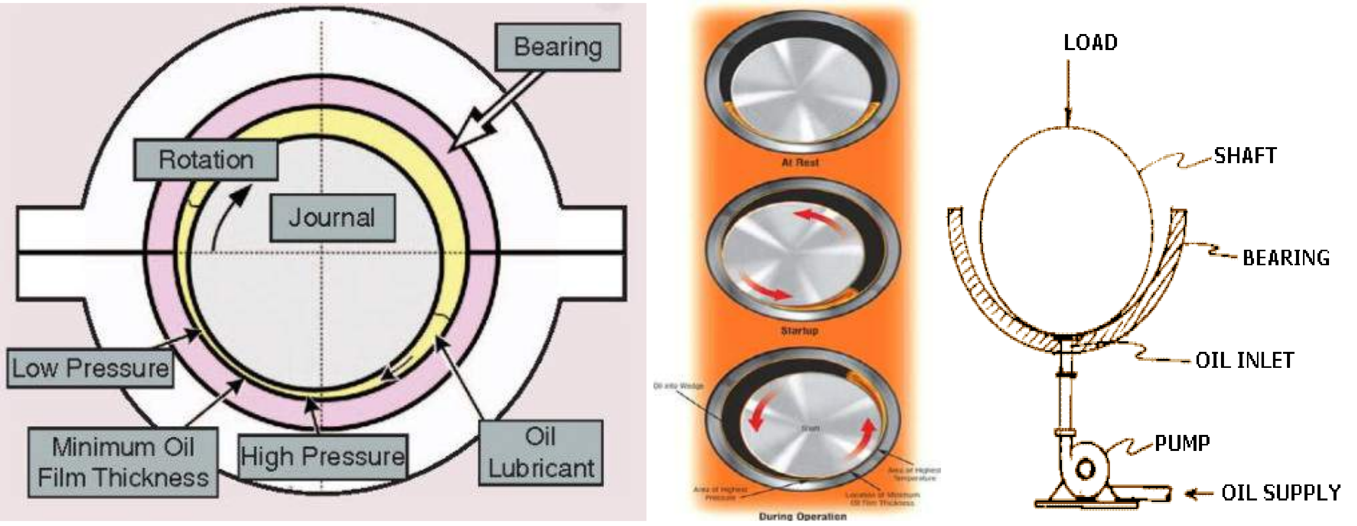
- **How do you check bearing crush?**

Plastic gauges can be used in two ways to measure bearing crush: along the axis of the shaft or circumferentially around the shaft

- **What do you mean by oil whirl or oil whip?**

The Phenomena Oil Whirl & Oil Whip happen inside Sleeve Brg, Rotor off at bottom position and have distance from center the rotor & center bearing as known as eccentricity. normally lube oil pressure to bearing 1.5 bar and when shaft start to rotate lube oil pressure inside bearing increase and it lift rotor to center bearing and oil also flow rotating following shaft rotation it create radial force & tangential force ( radial force ( force direction from bottom to center brg ) tangential force ( force direction from approx 45 degree from bottom to center brg ))normally radial force must higher than tangential force and when the tangential force higher than radial force will push rotor moving around the bearing and this phenomena we **called OIL Whirl** at vibration signal identified high vibration at less than half rotating speed, on orbit plot shape circular and appear more than blank/bright signal also precession direction is forward. Oil whip when the frequency oil whirl coincide with natural frequency it occur oil whip.

O**il whirl is probably the most common cause of sub synchronous instability in hydrodynamic journal bearings**. Typically, the oil film itself flows around the journal to lubricate and cool the bearing. This develops an average speed slightly less than 50 percent of the journal surface speed . Normally, the shaft rides on the crest of an oil pressure gradient, rising slightly up the side of the bearing somewhat off vertical at a given, stable attitude angle and eccentricity. The amount of rise depends on the rotor speed, rotor weight and oil pressure. With the shaft operating eccentrically relative to the bearing center, it draws the oil into a wedge to produce this pressurized load-carrying film.


Bearing
Rotation
Journal
Low Pressure
Minimum Oil Film Thickness
High Pressure
Oil Lubricant
At Rest
Startup
Oil into Wedge
Shaft
Area of Highest Pressure
Area of Highest Temperature
Location of Minimum Oil Film Thickness
During Operation
LOAD
SHAFT
BEARING
OIL INLET
PUMP
OIL SUPPLY

**Oil Film within a Journal bearing.**

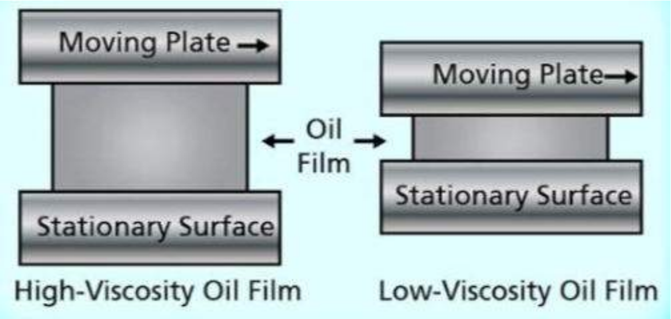
If the shaft receives a disturbing force such as a sudden surge or external shock, it can momentarily increase the eccentricity from its equilibrium position. When this occurs, additional oil is immediately pumped into the space vacated by the shaft. This results in an increased pressure of the load-carrying film, creating additional force between the oil film and shaft. In this case, the oil film can actually drive the shaft ahead of it in a forward circular motion and into a whirling path around the bearing within the bearing clearance. If there is sufficient damping within the system, the shaft can be returned to its normal position and stability. Otherwise, the shaft will continue in its whirling motion, which may become violent depending on several parameters.

- **Journal Bearings**

Industrial machinery with high horsepower and high loads, such as steam turbines, centrifugal compressors, pumps and motors, **utilize journal bearings as rotor supports**. One of the basic purposes of a bearing is to provide a frictionless environment to support and guide a rotating shaft. Properly installed and maintained, **journal bearings have essentially infinite life.**

**GEOMETRIES** -Journal bearings installed in industrial machinery today generally fall into two categories: full bearings and partial arc bearings. Full bearings completely surround the shaft journal with many differing geometries such as elliptical, lobed, or pressure dam configurations and usually are two pieces, mated at a split line. Partial arc bearings have several individual load bearing surfaces or pads and are made up of numerous adjustable components.

The bearing inner surface is covered with a softer material, commonly called babbit. **Babbit, which is a tin or lead based alloy**, has a thickness that can vary from 1 to 100 mils depending upon the bearing diameter. A Babbitt lining provides a surface which will not mar or gouge the shaft if contact is made and to allow particles in the lubricant to be imbedded in the liner without damaging the shaft.


Moving Plate
Oil Film
Stationary Surface
High-Viscosity Oil Film
Moving Plate
Stationary Surface
Low-Viscosity Oil Film

## BEARING DESIGN

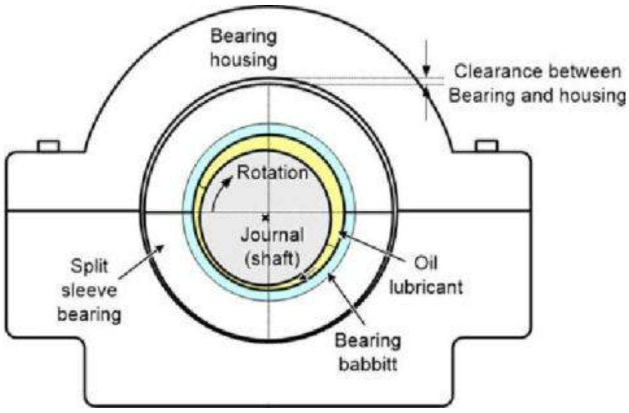
A journal bearing, simply stated, is a cylinder which surrounds the shaft and is filled with some form of fluid lubricant. In this bearing a fluid is the medium that supports the shaft preventing metal to metal contact. The most common fluid used is oil.This application note will concentrate on oil lubricated journal bearings. Hydrodynamic principles, which are active as the shaft rotates, create an oil wedge that supports the shaft and relocates it within the bearing clearances. In a horizontally split bearing the oil wedge will lift and support the shaft, relocating the centerline slightly up and to one side into a normal attitude position in a lower quadrant of the bearing. The normal attitude angle will depend upon the shaft rotation direction with a clockwise rotation having an attitude angle in the lower left quadrant. External influences, such as hydraulic volute pressures in pumps or generator electrical load can produce additional relocating forces on the shaft attitude angle and centerline position.

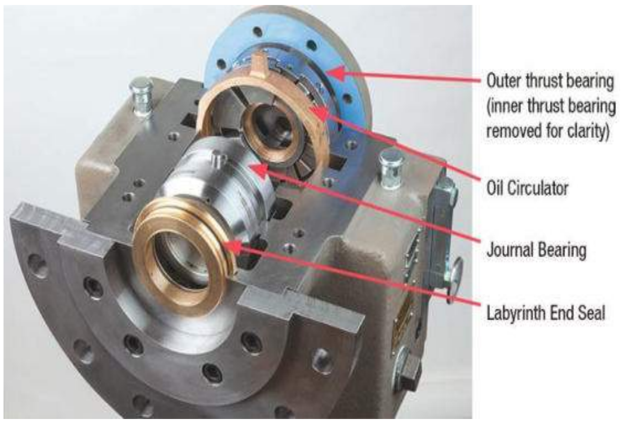
An additional characteristic of journal bearings is damping. This type of bearing provides much more damping than a rolling element bearing because of the lubricant present. More viscous and thicker lubricant films provide higher damping properties. As the available damping increases, the bearing stability also increases. A stable bearing design holds the rotor at a fixed attitude angle during transient periods such as machine startups/shutdowns or load changes. The damping property of the lubricant also provides an excellent medium for limiting vibration transmission. Thus, a vibration measurement taken at the bearing outer shell will not represent the actual vibration experienced by the rotor within its bearing clearances.

Journal bearings have many differing designs to compensate for differing load requirements, machine speeds, cost, or dynamic properties. One unique disadvantage which consumes much research and experimentation is an instability which manifests itself as oil whirl and oil whip. Left uncorrected, this phenomenon is catastrophic and can destroy the bearing and rotor very quickly. Oil whip is so disastrous because the rotor cannot form a stable oil wedge consequently allowing metal to metal contact between the rotor and the bearing surface. Once surface contact exists the rotor begins to process, in a reverse direction from rotor rotation direction, using the entire bearing clearance. This condition leads to high friction levels which will overheat the bearing babbit metal that leads to rapid destruction of the bearing, rotor journal, and the machine seals.

Some common designs employed are lemon bore, pressure dam, and tilt pad bearings. These designs were developed to interrupt and redirect the oil flow path within the bearing to provide higher bearing stabilities.

### Plain Bearing



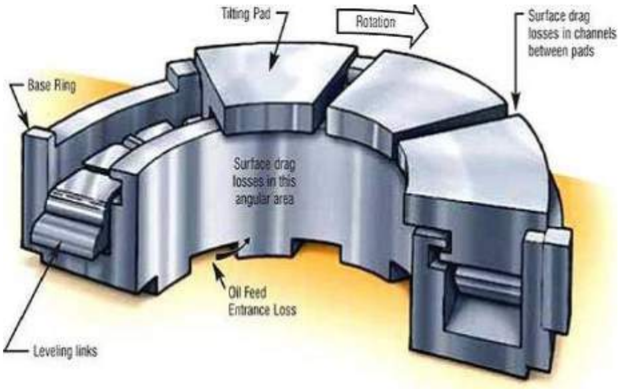

Outer thrust bearing (inner thrust bearing removed for clarity)
Oil Circulator
Journal Bearing
Labyrinth End Seal

The plain bearing is the simplest and most common design with a high load carrying capacity and the lowest cost. This bearing is a simple cylinder with a clearance of about 1-2 mils per inch of journal diameter. Due to its cylindrical configuration it is the most susceptible to oil whirl. It is a fairly common practice during installation to provide a slight amount of "crush" to force the bearing into a slightly elliptical configuration.

**Lemon Bore -** The lemon or elliptical bore bearing is a variation on the plain bearing where the bearing clearance is reduced on one direction. During manufacture this bearing has shims installed at the split line and then bored cylindrical. When the shims are removed the lemon bore pattern is results. For horizontally split bearings, this design creates an increased vertical pre-load onto the shaft. This bearing has a lower load carrying capacity that plain bearings, but are still susceptible to oil whirl at high speeds. Manufacturing and installation costs are considered low.

**Pressure Dam** A pressure dam bearing is basically a plain bearing which has been modified to incorporate a central relief groove or scallop along the top half of the bearing shell ending abruptly at a step. As the lubricant is carried around the bearing it encounters the step that causes an increased pressure at the top of the journal inducing a stabilizing force onto the journal which forces the shaft into the bottom half of the bearing. This bearing has a high load capacity and is a common correction for machine designs susceptible to oil whirl. Pressure dam bearings are a unidirectional configuration. Another unidirectional bearing configuration is the offset bearing. It is similar to a plain bearing, but the upper half has been shifted horizontally. Offset bearings have increasing load capacities as the offset is increased.

### Tilting Pad


Tilting Pad
Rotation
Surface drag losses in channels between pads
Base Ring
Surface drag losses in this angular area
Oil Feed Entrance Loss
Leveling links

Tilting pad bearings is a partial arc design. This configuration has individual bearing pads which are allowed to pivot or tilt to conform to the dynamic loads from the lubricant and shaft. This type of bearing is a unidirectional design and is available in several variations incorporating differing numbers of pads with the generated load applied on a pad or between the pads.

The simplest is the flat land thrust plate or washer, normally of Babbitt on steel. This can carry loads in the order of 0.34MPa (50 psi) and is often used mainly for axial location. Taper-Land bearings increase capacity by machining taper-lands into the surface, providing a defined converging geometry that can increase the specific load capacity to approximately 1.72 MPa (250 psi).The highest load capability is offered by the tilting pad thrust bearing which uses steel pads with a symmetrically positioned support pivot. Tilting pad designs commonly carry loads up to 4 MPa (580 psi).

### Bearing mounting methods :

1) **Bearing mounting kit :**

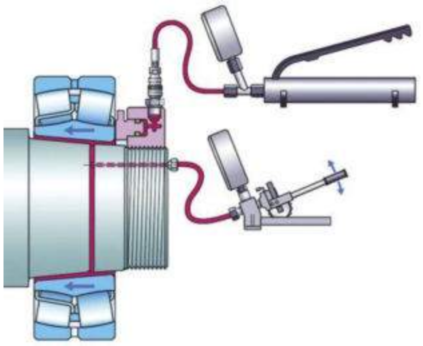
it is simple mechanical device used for fast , exact safe mounting of small ball and roller bearings whose inside diameter ranges from 10 to 50 mm . it consists of 33 plain machined , hardened and phosphate impact rings and 5 impact sleeve in a handy tool box . the impact sleeves are equipped with rubber o ring which keeps the two parts joined and makes it easy to combine different ring sizes to each sleeve .

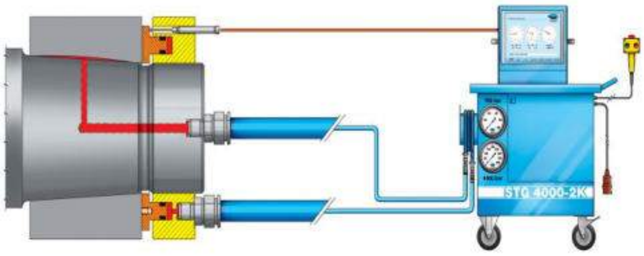
2) **Magnetic induction heater** :

An electrical appliance that works on the principle of magnetic induction. it is a simple , safe , fast and clean solution for mounting small and medium size bearings as well as other similar components **with interference fit on the shaft** (many other machine component can be heated with the help of this device such as coupling , hub , pulley , bush…). a bearing can be heated to the require temperature – 80 / 100 C and demagnetized in only 30 seconds . the device is provided with a timer an auto trip mechanism that saves the bearing from overheated .

3) **Electric hot plate** :

4) **Oil injected set** : oil injection method is widely used method for mounting and dismounting bearing with an interference fit ,the method involves the injection of oil under high pressure between the contact surfaces through ducts and distribution grooves . an oil film is thus formed over the whole seating surface so that the contact surface are fully separated from each other. Due to this the mounting and dis mounting force required is considerably reduced . the bearing can be easily mounted after correct adjustment , the oil pressure is reduced , the oil returns to the oil pump and bearing is firmly secured to the shaft .





- **Bearing first code :**

| first digit | types of the bearing |
|---:|---|
| 1 | double row self aligning ball bearing |
| 2 | double row spherical roller ball bearing |
| 3 | taper roller bearing |
| 4 | double row deep groove ball bearing |
| 5 | thrust ball bearing |
| 6 | single row deep groove ball bearing |
| 7 | single row angular contact ball bearing |
| 8 | cylindrical roller thrust bearing |
| N | cylindrical roller bearing ( N,NC,NF,NJ,NP,NU,NUP) |
| QJ | four point ball bearing ( split inner race ) |

- **What is hydrostatic lubrication?**

A type of lubrication in which moving surfaces are separated externally by a highly pressurized fluid such as air, oil, or water. Hydrostatic lubrication is expensive and its use is limited.

- **What is hydronamic lubrication?**

A type of lubrication in which a lubricant film completely separates two surfaces in contact. Hydrodynamic lubrication is achieved when a bearing rotates quickly enough for lubrication to flow around the bearing and cover its entire surface. **Hydrodynamic lubrication is also called full-fluid lubrication.**

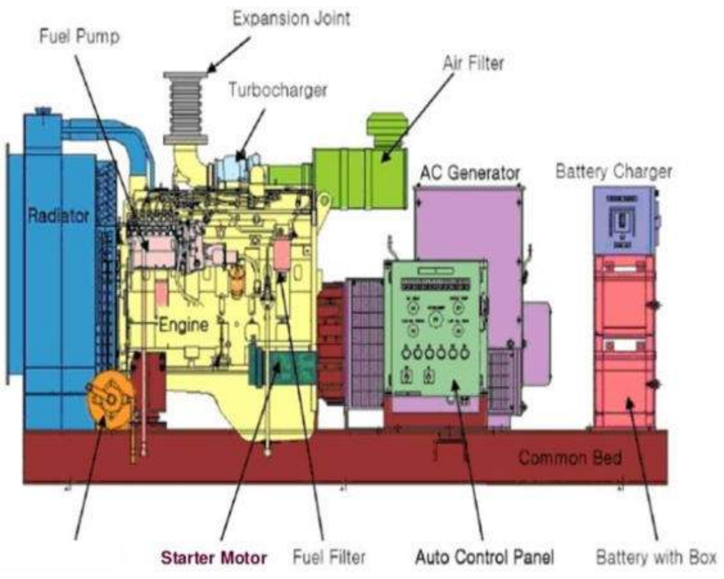
- **What is hydrodynamic bearing ?**

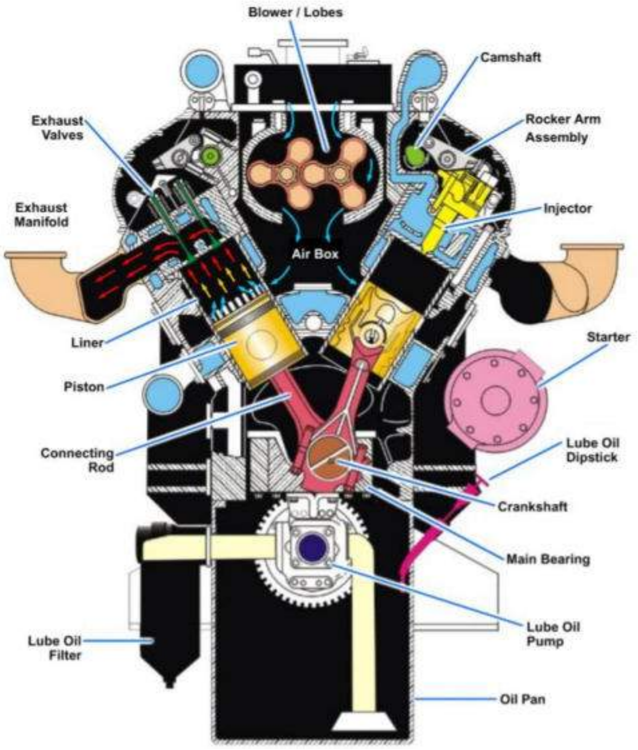
  A plain bearing operating using hydrodynamic lubrication. Hydrodynamic bearings are also called fluid film bearings.

- **What is force feed lubrication?** Force feed lubrication systems are designed to accurately deliver, monitor, and protect oil delivery to pumps, compressors or any other equipment. A system is usually comprised of a divider block which automatically directs the oil to several points, a lubricator pump to deliver the oil under sometimes very high pressure and a computer to monitor the flow of the oil, to give totals, averages, alarms, etc.

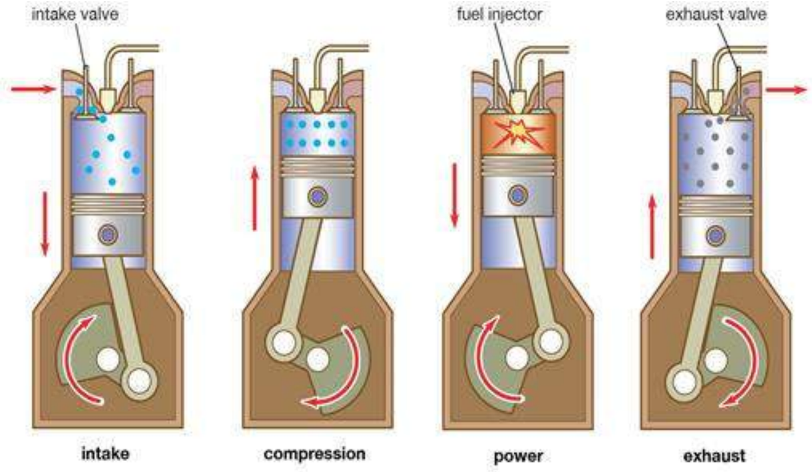
**What is dummy bearing?** Apparatus for detecting wear on radial or thrust bearings. Bearing clearances are monitored by observing clearances generated by dummy bearings structured to wear like the actual bearings and installed in proximity there to and designed so that their clearances may be readily determined by direct inspection. A dummy bearing for indicating the state of wear of a bearing journaling a shaft in a support comprising

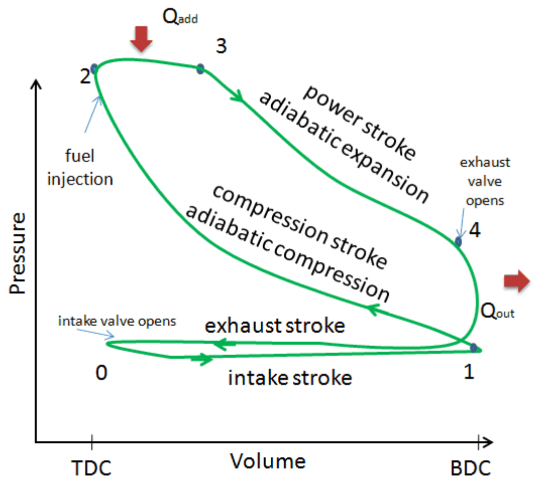
# DIESEL ENGINE:


Fuel Pump
Expansion Joint
Turbocharger
Air Filter
Radiator
AC Generator
Battery Charger
Engine
Common Bed
Starter Motor
Fuel Filter
Auto Control Panel
Battery with Box


Blower / Lobes
Camshaft
Exhaust Valves
Rocker Arm Assembly
Exhaust Manifold
Injector
Air Box
Liner
Starter
Piston
Connecting Rod
Lube Oil Dipstick
Crankshaft
Main Bearing
Lube Oil Pump
Lube Oil Filter
Oil Pan

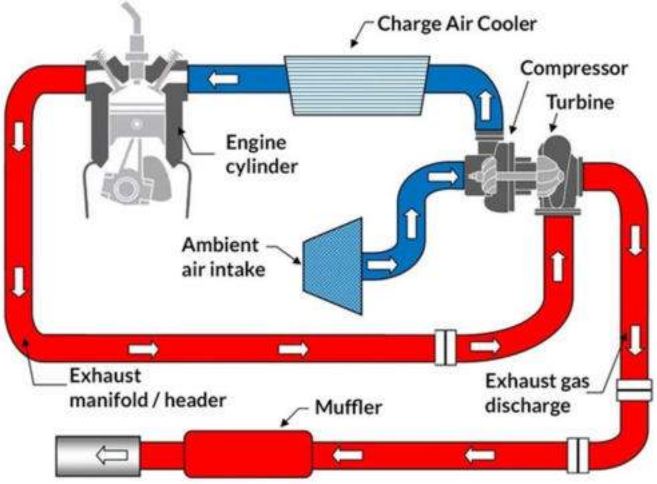
## Diesel engine working flow

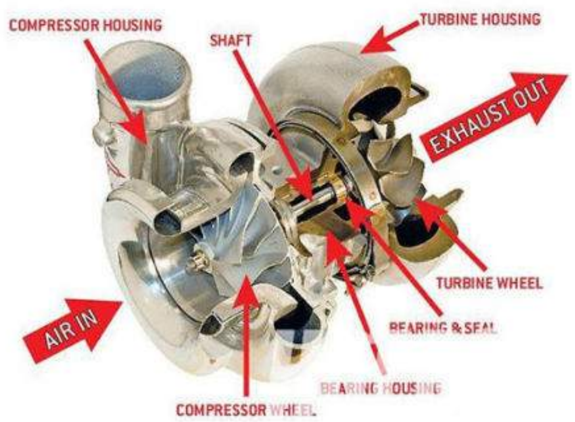

intake valve
fuel injector
exhaust valve
intake
compression
power
exhaust



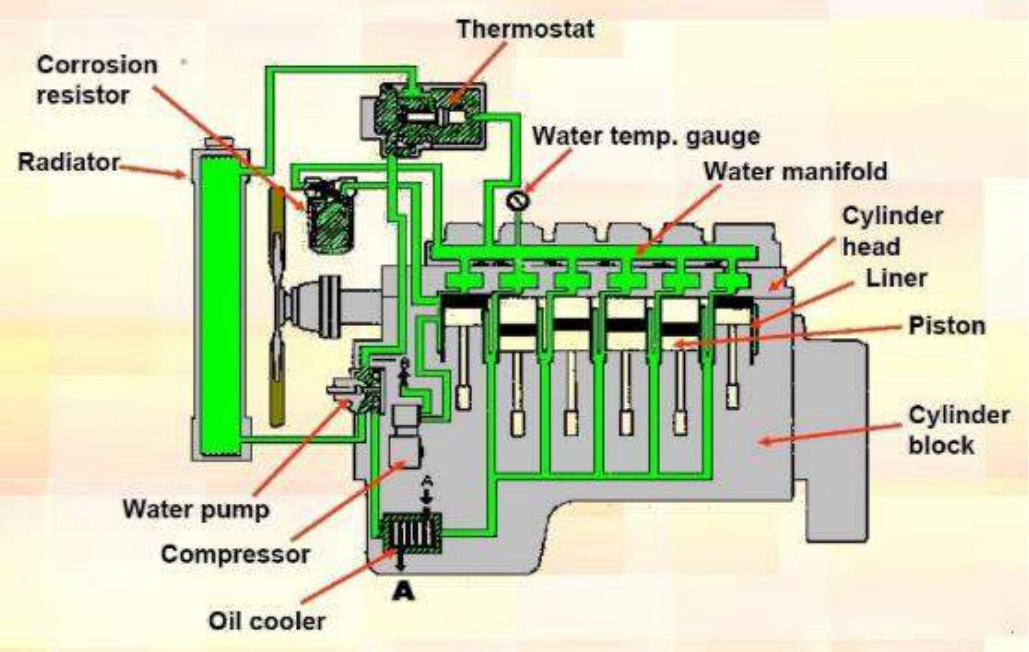
## What to check?

### 1) Air circuit / turbocharger working flow

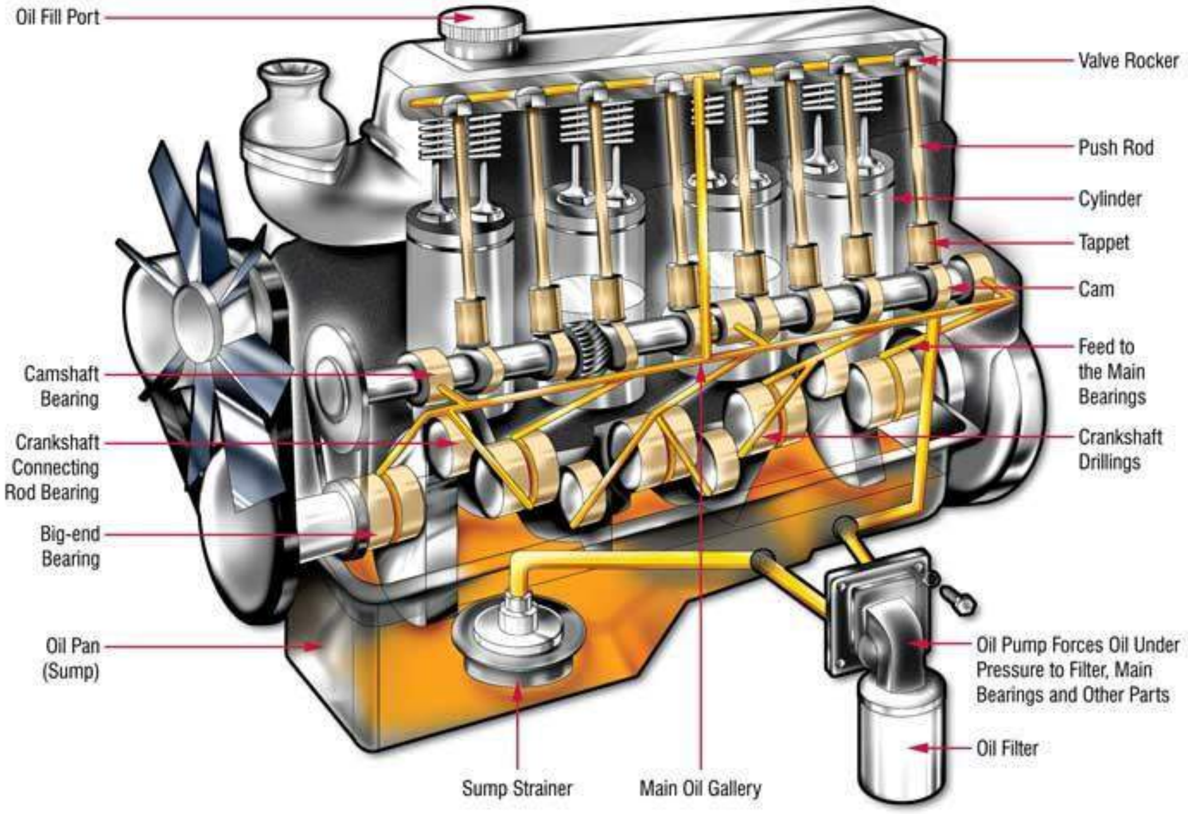

Charge Air Cooler
Compressor
Turbine
Engine cylinder
Ambient air intake
Exhaust manifold / header
Muffler
Exhaust gas discharge


COMPRESSOR HOUSING
SHAFT
TURBINE HOUSING
EXHAUST OUT
AIR IN
TURBINE WHEEL
BEARING & SEAL
BEARING HOUSING
COMPRESSOR WHEEL

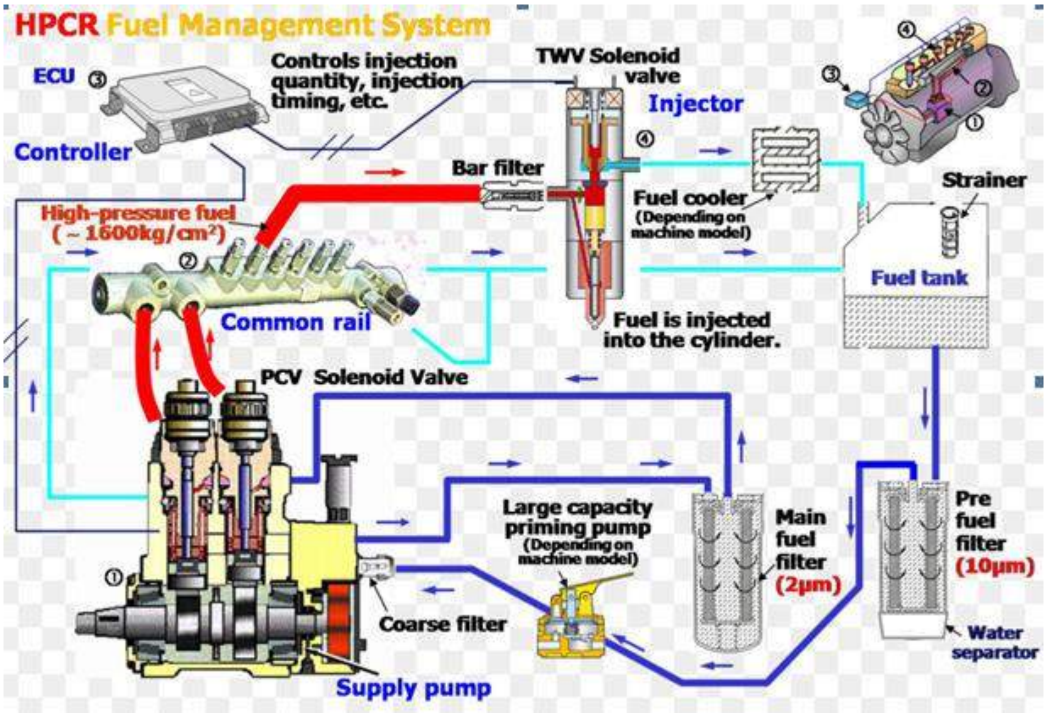
## 2) cooling circuit


Thermostat
Corrosion resistor
Radiator
Water temp. gauge
Water manifold
Cylinder head
Liner
Piston
Cylinder block
Water pump
Compressor
A
Oil cooler

## 3) lubrication circuit


Oil Fill Port
Valve Rocker
Push Rod
Cylinder
Tappet
Cam
Feed to the Main Bearings
Camshaft Bearing
Crankshaft Connecting Rod Bearing
Crankshaft Drillings
Big-end Bearing
Oil Pan (Sump)
Oil Pump Forces Oil Under Pressure to Filter, Main Bearings and Other Parts
Oil Filter
Sump Strainer
Main Oil Gallery

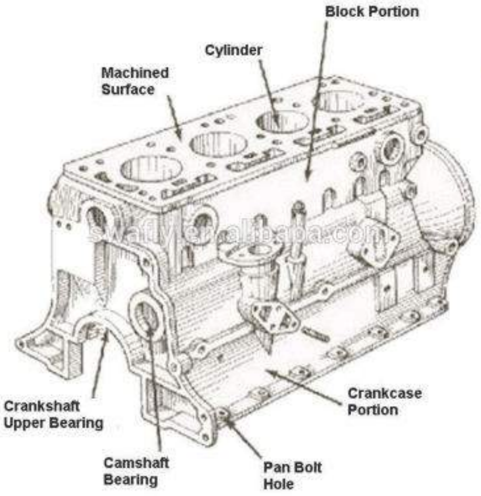
## 4) Fuel circuit

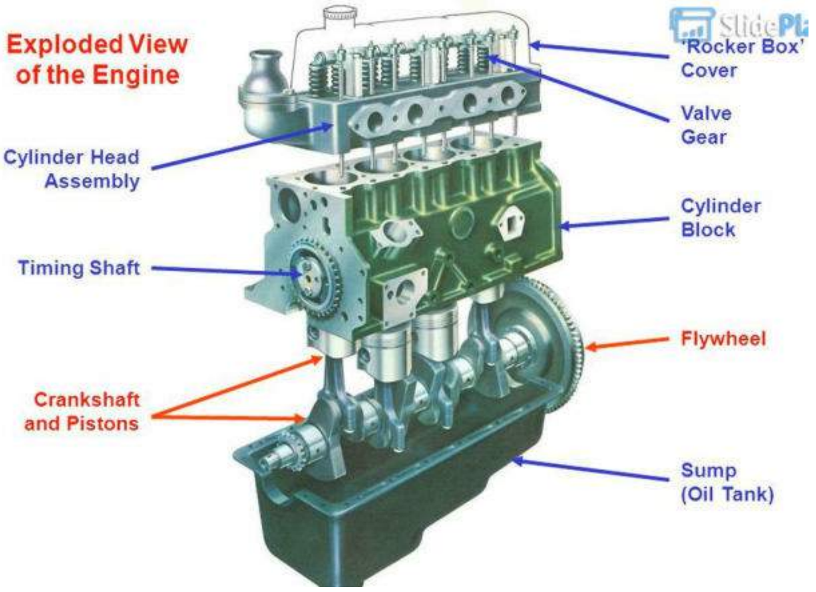

HPCR Fuel Management System
ECU ③
Controls injection quantity, injection timing, etc.
TWV Solenoid valve
Injector
④
③
②
①
Controller
Bar filter
④
Fuel cooler (Depending on machine model)
Strainer
High-pressure fuel (~1600kg/cm²)
②
Common rail
Fuel tank
Fuel is injected into the cylinder.
PCV Solenoid Valve
Large capacity priming pump (Depending on machine model)
Main fuel filter (2µm)
Pre fuel filter (10µm)
Water separator
①
Coarse filter
Supply pump

## DG SET MAINTENANCE

### How to Overhaul a Diesel Engine

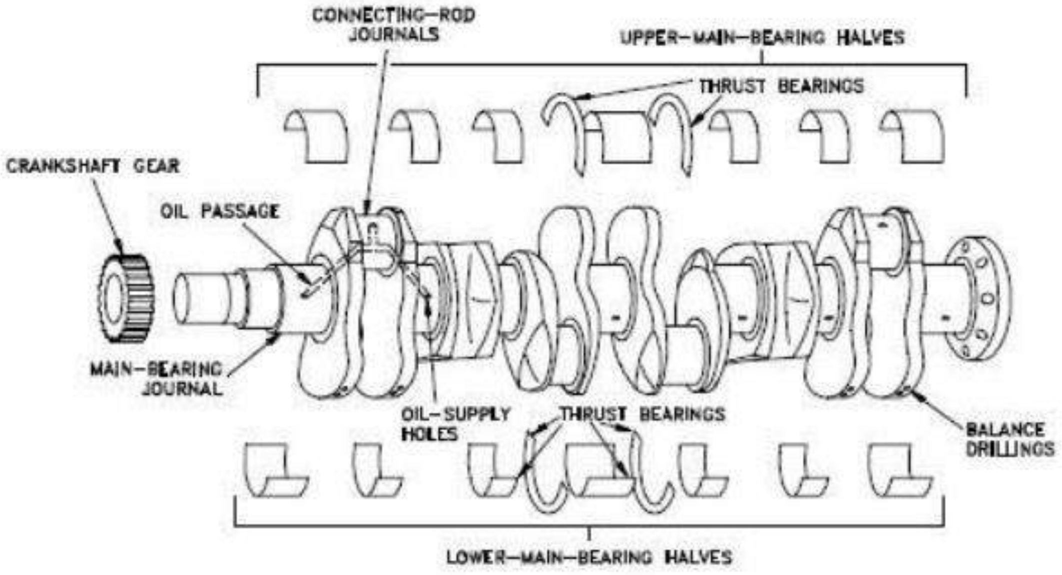
1] Engine **block or cylinder block** – is considering the" backbone" of the engine to which all other parts are bolted or attached. Some manufacturers mass produced engine blocks but some made it one at a time for special cases. They used compacted sand and resin or sand cast to be its mold. They put a thin amount of carbon (by torch) that acts as a lubricant so that the molten metal will flow smoothly to the spaces of the sand cast. The raw molten metal is heated about 1300 deg. F before it will be poured in to the cast. After some time it will become a super strong aluminum alloy. They used powerful x-ray to scan the engine block to see if there is any a microscopic crack or floss in the metal. Slight vibration from a defect in the engine will be magnified at high speed and the engine could fail.


Block Portion
Cylinder
Machined Surface
Crankshaft Upper Bearing
Camshaft Bearing
Pan Bolt Hole
Crankcase Portion


Exploded View of the Engine
'Rocker Box' Cover
Valve Gear
Cylinder Head Assembly
Cylinder Block
Timing Shaft
Flywheel
Crankshaft and Pistons
Sump (Oil Tank)

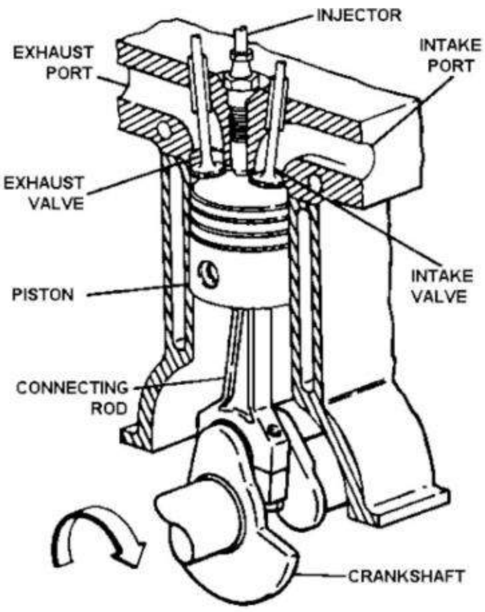
2] **Cylinder Head and valve** – It provides a passageway that allows air into the cylinder and allows the exhaust gases to pass-out. These parts opened and closed by puppet type valves, that fits into the guide in the cylinder.

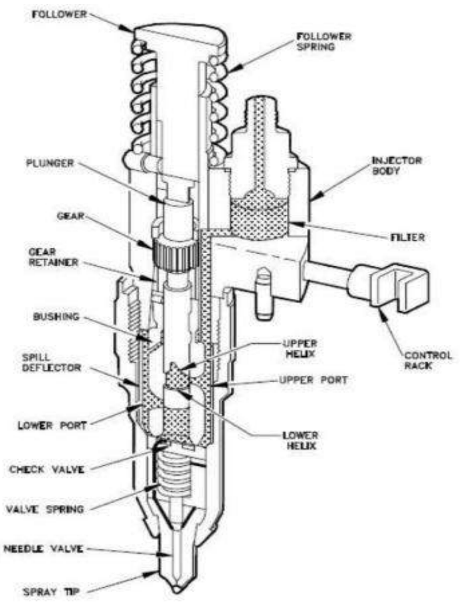
3] **Crankshaft** – a long shaft inserted in the bottom of the block with offset crankpin, It is used to translate the reciprocating linear motion of the piston in to a rotational motion or simply to convert the reciprocating motion in to rotation

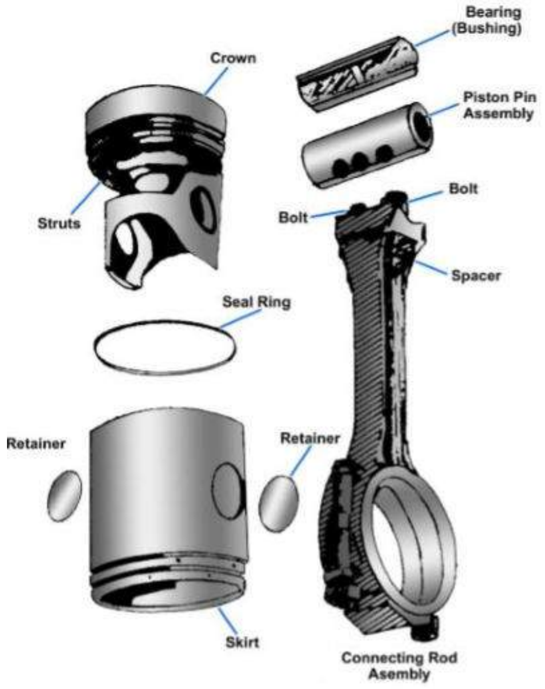

CONNECTING-ROD JOURNALS
UPPER-MAIN-BEARING HALVES
THRUST BEARINGS
CRANKSHAFT GEAR
OIL PASSAGE
MAIN-BEARING JOURNAL
OIL-SUPPLY HOLES
THRUST BEARINGS
BALANCE DRILLINGS
LOWER-MAIN-BEARING HALVES

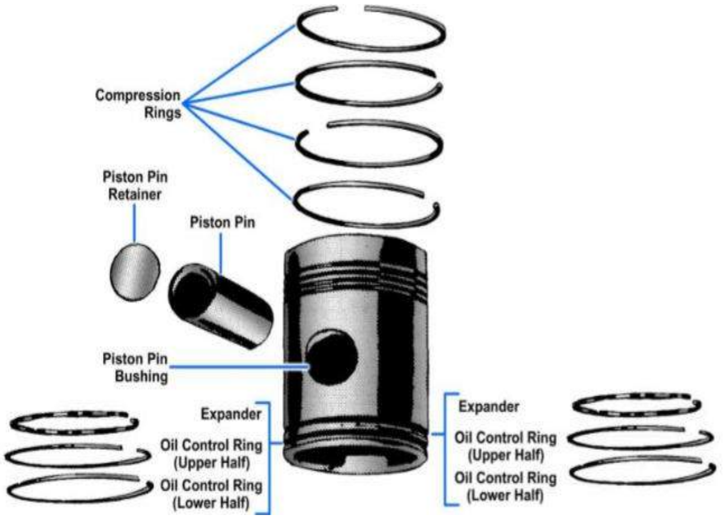
4] **Cylinder Sleeve Liner** – most diesel engine use a replaceable cylinder sleeve so that it can be replaced easily. There are liner less type in which the cylinder block itself is machined in the engine block like in the picture.

5] **Piston rings** - a semi keystone ring is used for no 1 compression ring and a tapered ring or tapered under-cut ring is used for no. 2 compression ring, but a solid ring with coil or a three- piece ring is usually used for the oil ring.

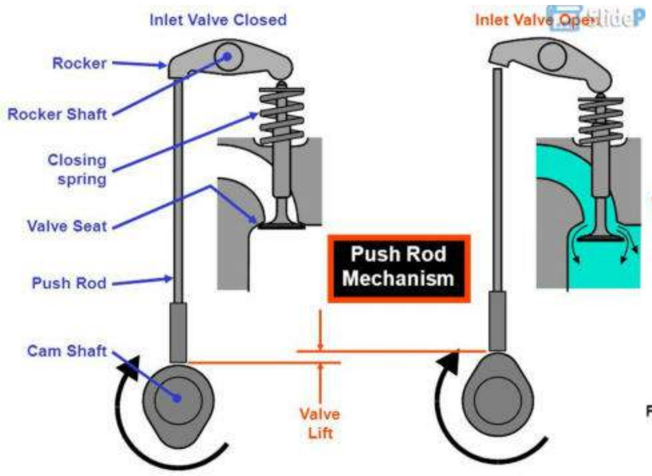

INJECTOR
EXHAUST PORT
INTAKE PORT
EXHAUST VALVE
PISTON
INTAKE VALVE
CONNECTING ROD
CRANKSHAFT

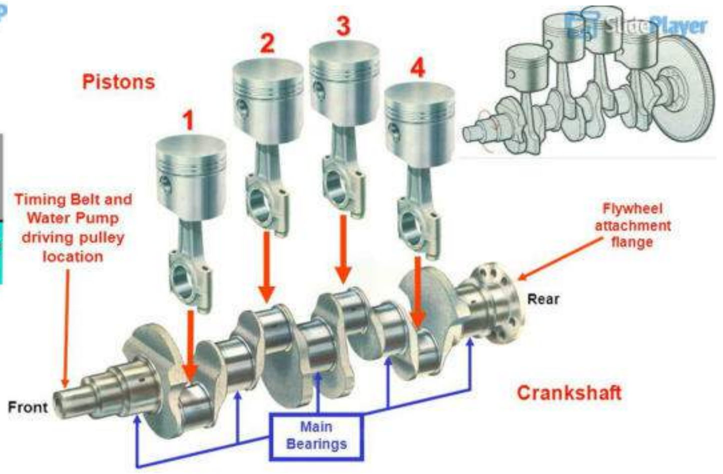

FOLLOWER
FOLLOWER SPRING
PLUNGER
INJECTOR BODY
GEAR
FILTER
GEAR RETAINER
BUSHING
UPPER HELIX
CONTROL RACK
SPILL DEFLECTOR
UPPER PORT
LOWER PORT
LOWER HELIX
CHECK VALVE
VALVE SPRING
NEEDLE VALVE
SPRAY TIP


Bearing (Bushing)
Crown
Piston Pin Assembly
Struts
Bolt
Bolt
Spacer
Seal Ring
Retainer
Retainer
Skirt
Connecting Rod Asembly


Compression Rings
Piston Pin Retainer
Piston Pin
Piston Pin Bushing
Expander
Oil Control Ring (Upper Half)
Oil Control Ring (Lower Half)
Expander
Oil Control Ring (Upper Half)
Oil Control Ring (Lower Half)

**6] Rocker Arm and Push Rod** – it transmit the cam action of the crank shaft to the engine valves causes them to close or to open.


Inlet Valve Closed
Inlet Valve Open
Rocker
Rocker Shaft
Closing spring
Valve Seat
Push Rod
Cam Shaft
Push Rod Mechanism
Valve Lift


Pistons
1
2
3
4
Timing Belt and Water Pump driving pulley location
Flywheel attachment flange
Rear
Front
Crankshaft
Main Bearings

**7] Oil pan** - it is the reservoir for the oil, located in the bottom cover of the engine.

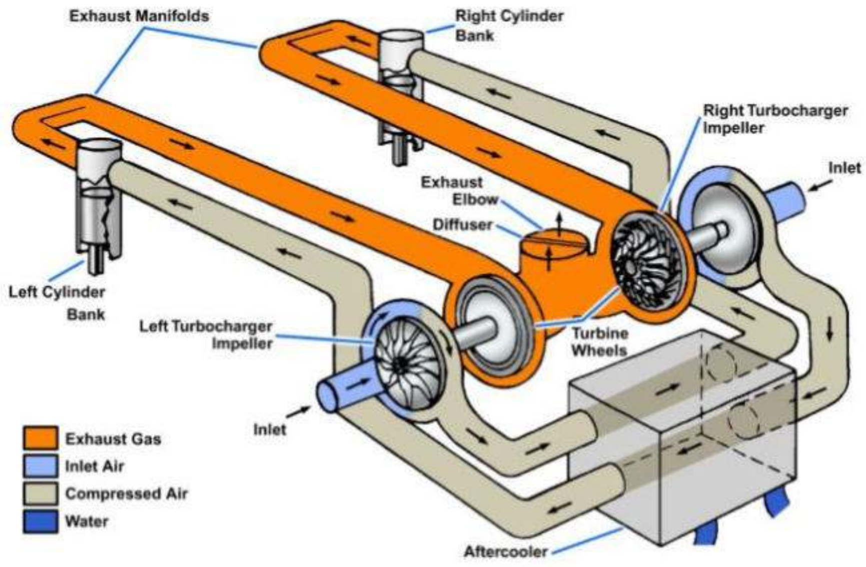
**8] Oil Pump** – it supply oil under pressure. It draws oil from the reservoir to the oil nozzles. Bearings and other parts that needs lubrication.

**9] Water Pump** – this pumps water to the radiator to the engine block, oil cooler and other parts that needs cooling.

**10] Oil Cooler** – A device used to cool the engine oil during engine operation. Allows the coolant water and engine oil to circulate simultaneously without being mixed.

**11] Fly Wheel** – A heavy metal wheel bolted on to gear of the crank shaft that provide a place to mount the starter ring gear and transmission clutch.

**12] Intake Manifold** – Bolted on the cylinder head assembly that provides a passage way for the clean air to enter the combustion chamber.

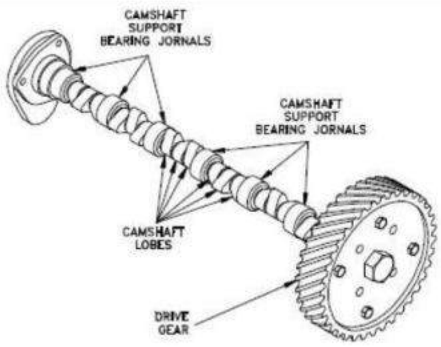

Exhaust Manifolds
Right Cylinder Bank
Right Turbocharger Impeller
Inlet
Exhaust Elbow
Diffuser
Left Cylinder Bank
Left Turbocharger Impeller
Turbine Wheels
Inlet
Exhaust Gas
Inlet Air
Compressed Air
Water
Aftercooler

**13] Exhaust Manifold** – This is where the exhaust gas exits from the chamber going to the muffler.

**14] Injection pump** – It injects the right amount of fuel at the right time with extreme precise and tolerances. Fuel must be injected at particular crankshaft angle before top dead center (BTDC) of the compression stroke of the piston. Timing belt or timing gear is used to power the pump with exact timing when to deliver the fuel in to the chamber. Fuel is injected at pressure approximately 2000 psi as it is needed for the hot and compressed air to ignite the mixture that creates the power to push the piston downward.

**15] Starter –** Used to crank the engine for start-up.

**16] Camshaft** – It transmit the cam action of the crankshaft for the valves to open and close in the right time as needed. The relationship of camshaft and crankshaft is very important to an engine. The valves control the flow of air intake and exhaust gasses. For this purpose camshaft is connected to crankshaft either directly by a timing gear, by a timing belt or by a timing chain. Depending on the position of the camshaft, the cams operate the valves directly or by the use of a push rod and rocker arm. Direct operation of the cam to the valve is much simpler valve mechanism. It leads to fewer parts needed and which means fewer mechanism to fail. It will require that the camshaft is to be positioned at the top of the cylinder.


CAMSHAFT SUPPORT BEARING JORNALS
CAMSHAFT SUPPORT BEARING JORNALS
CAMSHAFT LOBES
DRIVE GEAR

## DG SET MAINTENANCE PLAN

| DG SET MAINTENANCE PLAN |
|---|
| **PM ( NORMAL SERVICE AT 400 - 500 WORKING HOURS ) OR 06 MONTH** |
| **JOB DESCRIPTION** |
| Air filter change |
| Oil filter change |
| Oil replacement |
| Fuel filter change |
| Radiator cleaning |
| Coolant change or top up |
| **TOP END OVERHAULING - 11000 TO 15000 WORKING HOURS** |
| Turbo charger service |
| Fuel injectors service |
| Cylinder Head service |
| Valves |
| Rocker arms |
| Main bearing |
| **MAJOR OVERHAULING -22000 - 27000 WORKING HOURS** |
| Above all points plus …below |
| Change / check connecting rod & crank shaft Bearing |
| Change / check fuel injector nozzles |
| Change Main bearing |
| Check Cylinder / linear , piston ring change |
| Turbo charger service or replace |
| Timing belt/ chain / check shaft |
| Water ,Oil & Fuel pump change /service |
| Radiator service |
| Engine to generator coupling |
| Change Valves |

### Inspection, Reconditioning or replace of Components

Inspect the following components according to the instructions that are in IOM-manual. Recondition the worn components or replace the components, if necessary. Dealer can provide these services and components / spares.

- Camshaft followers
- Connecting rods
- Cylinder head assembly
- Cylinder liners
- Engine wiring harness
- Exhaust bellows
- Fuel transfer pump
- Oil pump
- Pistons
- Piston ring & pins
- lube oil pump
- Turbochargers
- Camshaft
- Camshaft bearings
- Crankshaft
- Crankshaft thrust washers
- Driven equipment (alignment with …..)
- Gear train bushings and bearings
- Water pump

### Cleaning of Components

Clean all parts properly with solvent & for cooler (if available). refer Operation and Maintenance Manual for pressure tests & cleaning of the coolers .

### Coolant Analysis

More than 40% of all engine troubles begin with cooling system problems. Once these problems start, they spread through your engine, transmission, and hydraulic system. As a result, power is drained, productivity is decreased, and major breakdowns can occur. Coolant Analysis detects potential problems before damage occurs. It is a two-level analysis that verifies the proper make-up of your coolant and diagnoses the condition of your cooling system. This allows you to correct coolant deficiencies inexpensively before costly problems arise.

Level 1, is recommended after every 500 hours of machine operation.
Level 2 is recommended every 1,000 hours, or a minimum of once a year or as dictated by Level 1.

**Level 1** is a basic coolant maintenance check. It determines if the coolant has the right balance for proper heat and corrosion/erosion control. The tests performed check for glycol level (freeze & boil protection), SCA (Supplemental Coolant Additives ) concentration (corrosion/erosion protection), pH (acid level), and conductivity.

**Level 2** is a comprehensive cooling system analysis. It includes all of the Level 1 tests and goes one step further. It completely analyzes the coolant and its effect upon the cooling system. The tests identify metal corrosion, other contaminants, and built-up impurities which point to corrosion and scaling problems before they lead to more costly repairs. Contact your nearest dealer for more details.

**Oil analysis** OA is the laboratory analysis of a lubricant's properties, suspended contaminants, and wear debris. OA is performed during routine predictive maintenance to provide meaningful and accurate information on lubricant and machine condition. By tracking oil analysis sample results over the life of a particular machine, trends can be established which can help eliminate costly repairs. The study of wear in machinery is called tribology. Tribologists often perform or interpret oil analysis data.
**OA can be divided into three categories:**

1. analysis of oil properties including those of the base oil and its additives,
2. analysis of contaminants,
3. analysis of wear debris from machinery

**What is ppm oil analysis?**

TAN (Total Acid Number) typically; new engine **oils** have low TAN's of less than 2. If the used **oil** shows an increase of double the values of the new **oil**, it indicates a need to change the **oil**. Elemental **analysis** will have different levels of allowable **parts per million** (**ppm**) for different types of equipment/engines.

**What does CC Stand for?** CC is the abbreviated form of cubic centimeter. It is the unit by which the capacity of an engine is designated. It is the volume between TDC and BDC. It represents the quantity of fuel-air mix or exhaust gas that is pumped out in a single piston stroke. Cubic Capacity is volume of cylinder in which piston move.

**What is more efficient between 2 stroke & 4 stroke engine?** 4stroke engine is thermally efficient than 2stroke engine but 2stroke engine is mechanically efficient than 4stroke engine.

- **Why Flywheel is used (Need technical answer)? Why generally flywheel is big in shape?**

Flywheel is used to store energy the power stroke. Because after the power stroke the energy needed by the piston to complete the other three stroke will be given by the flywheel. That’s why to store a big amount of energy the size of flywheel is kept big.

- **What is the difference between clutch and brake?** In vehicle -Clutch is used to connect or disconnect an engine with gearbox . It is operated during gear shifting. while brakes are used to slow down the speed or stop the vehicle suddenly

- **What will happen if petrol is fed to diesel engine and diesel is fed to petrol engine? In any case engine will run or not?**

**Both the engines will not work ,** petrol engine will not work on diesel. in diesel engine there is no sparkplug to ignite petrol so petrol can't be used .in petrol engine there is no injector to inject diesel so it can't be used.

**Why alcohol can’t be used as a fuel in diesel engine?** Alcohol can’t be used as fuel in diesel engines because **1)** The engine should modified first, that is the enlargement of the carburetor jet(s) **2)** In addition to the carburetor jets, there is also the problem of cold starting. **3)** Alcohol has a higher latent heat of vaporization than gasoline and requires more manifold heat to keep the mixture in the vapor state. **4)** The main problem is in the lubrication of the injectors.

## Safety valve:

All equipment's, vessels, piping etc. work under certain pressure and are designed for certain maximum pressure. A pressure that goes beyond this value is dangerous for the equipment/piping and harmful for the plant and personnel. A pressure relief valve is a device which is nothing but an automatic spring loaded pressure relieving valve actuated by the static pressure. As the system pressure goes beyond certain preset value, the pressure relief valve pops open quickly. It recloses when the system pressure is lowered with minimum loss of fluid. Hence, the pressure relief valve is closed when the process operates normally within its pressure limit.

**There are three basic types of Pressure Relief Valves**:

- **Safety Valves**: These are used for steam and fire services. Their characteristic feature is fast popping action.
- **Safety Relief Valves**: These are also characterized by rapid popping action, but performance requirements of these valves are not as stringent as Safety Valves. They are used for steam, air, gas, vapours and fluids.
- **Relief Valves**: They are used mostly for gases, vapours and liquid services including thermal relief.

**Above all of these valves are practically similar in structure, design and performance.**

**Nozzle:** It is screwed to the body. Its top face is lapped and acts as a seat on which the lapped disc is seated. Many times, nozzles are provided with nozzle ring.

**Disc :** It is also having a lapped face and seats on the nozzle. Disc is attached to the stem and is pressed against the nozzle with the help of a valve spring.

**Spring** provides static pressure which makes the disc sit on the valve seat against the opening forces like system pressure.

**Spring Adjusting Screw**: It is used to adjust the spring tension which in turn decides the set pressure of the valve.

The disc-holder may have a blow down ring. The shape of disc holder and position of nozzle ring as well as blow down ring control the valve action such as - accurate opening, full lift and proper blow down.

The inlet flange and the nozzle are directly subjected to the system pressure, whereas the outlet flange subjects to the lesser pressure since valve either discharges to the atmosphere or to a lower pressure system. That is the reason for inlet flange to be bigger than the outlet flange.

**Relief valve (RV):** an automatic system that is actuated by the static pressure in a liquid-filled vessel. It specifically opens proportionally with increasing pressure.

**Safety valve (SV):** an automatic system that relieves the static pressure on a gas. It usually opens completely, accompanied by a popping sound.

**Safety relief valve** (SRV): an automatic system that relieves by static pressure on both gas and liquid.

**Pilot-operated safety relief valve** (POSRV): an automatic system that relieves on remote command from a pilot, to which the static pressure (from equipment to protect) is connected.

**Low pressure safety valve** (LPSV): an automatic system that relieves static pressure on a gas. Used when the difference between the vessel pressure and the ambient atmospheric pressure is small.

**Vacuum pressure safety valve** (VPSV): an automatic system that relieves static pressure on a gas. Used when the pressure difference between the vessel pressure and the ambient pressure is small, negative and near to atmospheric pressure.

**Low and vacuum pressure safety valve** (LVPSV): an automatic system that relieves static pressure on a gas. Used when the pressure difference is small, negative or positive and near to atmospheric pressure.

**RV, SV and SRV are spring-operated (even spring loaded). LPSV and VPSV are spring-operated or weight-loaded.**

### OPERATION OF A PRESSURE RELIEF VALVE:

Normal working pressure of equipment should be 10% less than the set pressure of the pressure relief valve, at which valve starts opening. The spring pressure acts normal working pressure of equipment should be 10% less than the set pressure of the pressure relief valve, at which valve starts opening. The spring pressure acts downwards, whereas operating pressure acts upwards on the disc. The pressure differential tends to keep the valve closed.

When the operating pressure increases and approaches the set pressure, the valve starts to open.

**Expansive Lift:** As spring pressure is reached and exceeded, the disc starts to open. The compressible fluid expands and escapes. During escape, it is diverted by the nozzle ring upwards against the secondary larger area causing immediate increase in lifting force. Because of this, the valve pops open to lift approximately 70% of the full lift.

**Reactive lift:** The remaining lift is provided by the additional reactive force, as the fluid is directed downwards from the disc to the secondary orifice formed by the nozzle ring and the disc holder.
As the pressure drops, spring force overcomes the lifting force caused by the fluid pressure and tends to move the disc in the downward direction. The escaping fluid holds the disc open to a point approximately 5 to 7% below the set pressure. **The difference between set pressure and the closing pressure is called 'blow down'.**

**Maintenance: Some common leakage problems are**:

1) Seat damaged by solid particles while discharging,
2) Distortion transmitted to seating area from piping load,
3) Operating pressure too close to set pressure,
4) Incorrect maintenance or testing,
5) Incorrectly adjusted lifting gear.

Faulty installation may cause chattering, Hang-up and galling

**There are three main reasons for chattering**:
**Excess valve capacity**: The selected orifice is too large for the required capacity of the vessel or equipment being protected, and the valve is 'starved'. In this case, as valve pops, large amount of fluid escapes and disc bangs on the seat.
**Excessive pressure drop in the inlet piping**: In this case, the valve will not sense actual pressure in the vessel which may be dangerous.
**Discharge piping too small:** Discharge piping should either be equal to or greater than relief valve outlet.
**Hang up** (or sticking open) may be caused by galling in the guiding area either because of solid particles or improperly supported discharge piping. All discharge piping should be supported independently of the valve.

**Assembly:**

1) Screw the nozzle in the body if it was removed. Screw the nozzle ring and adjust it below the top surface of the nozzle seat.
2) Fit the guide with guide ring in the body facing the vent hole towards the outlet.
3) Place the disc and the spindle assembly in the guide.
4) Place the spring with its washers and bonnet gasket.
5) Put the bonnet on the body and tighten the nuts evenly to prevent the stress or misalignment.
6) Screw down the adjusting bolt to the original measurement taken while dismantling the valve.
7) Adjust the guide ring so that the bottom surface is in level with the outside edge of the guide. Screw up the nozzle ring till it touches the disc and back it down by two notches. Tighten the set screws. This is a test stand setting only.

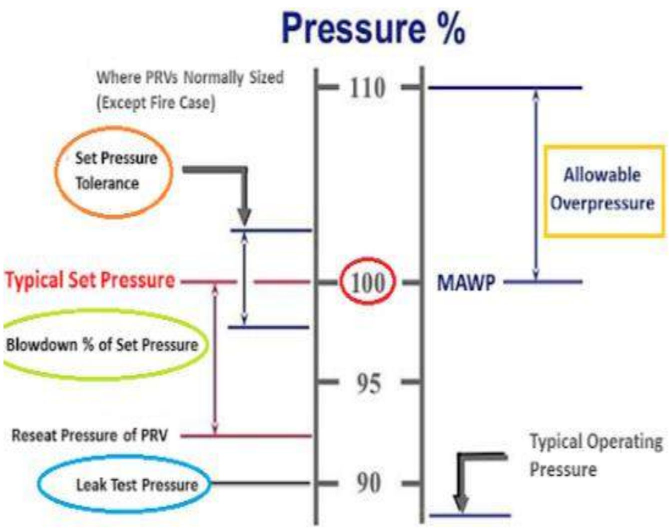
**Testing and Adjustments**: After reconditioning of the valve, it is necessary:

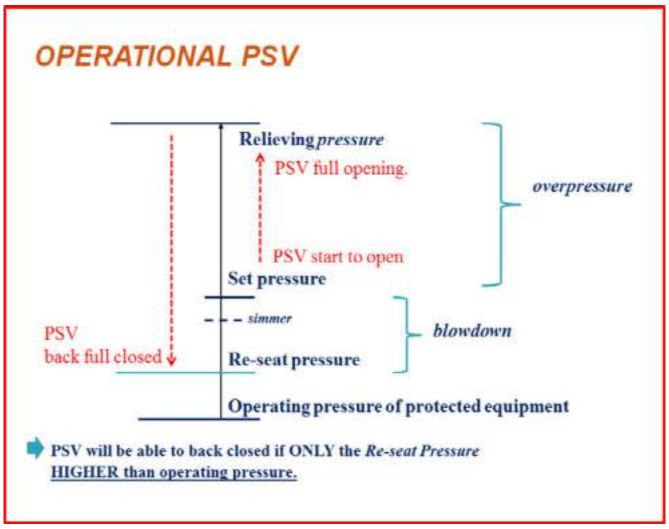
1) To re-adjust the set pressure and
2) Check the Tightness.

**Testing medium used may be air, nitrogen or water, but it should be clean and free from any solid particles.**

**Set pressure** = spring pressure + back pressure.

**Tightness Test:**
This can be performed by putting water on the discharge side as the testing medium, under pressure on the inlet side. When assembled properly, satisfactory tightness can be obtained to pressure 10% below the set pressure.
This test can also be performed by blanking the outlet flange with a blind flange, with a small tube connected to it. The tube outlet is submerged in water to check for the bubbles.The leakage rate of bubbles per minute should not exceed max. 25-30 bubble per minute


Pressure %
Where PRVs Normally Sized
(Except Fire Case)
Set Pressure
Tolerance
110
Allowable
Overpressure
Typical Set Pressure
100
MAWP
Blowdown % of Set Pressure
95
Reseat Pressure of PRV
Typical Operating
Pressure
Leak Test Pressure
90


OPERATIONAL PSV
Relieving pressure
PSV full opening.
overpressure
PSV start to open
Set pressure
simmer
PSV
back full closed
blowdown
Re-seat pressure
Operating pressure of protected equipment
PSV will be able to back closed if ONLY the Re-seat Pressure
HIGHER than operating pressure.

## Safety valves:

The American Petroleum Institute (API) has published codes and standards for sizing, selection, installation and inspection of pressure relief devices.

### TYPES OF DEVICES AND VALVES

A pressure relief device is actuated by inlet static pressure. It is designed to open during emergency or abnormal conditions to prevent a rise of internal fluid pressure over a specified value or set pressure. The devices are used on all types of pressurized equipment. The purpose of these devices is to protect a vessel/piping against overpressure.

Many types of pressure relief devices are available in the market today. **The main types of pressure relief devices are: reclosing and nonreclosing pressure relief devices.**

### Reclosing Pressure Relief Devices

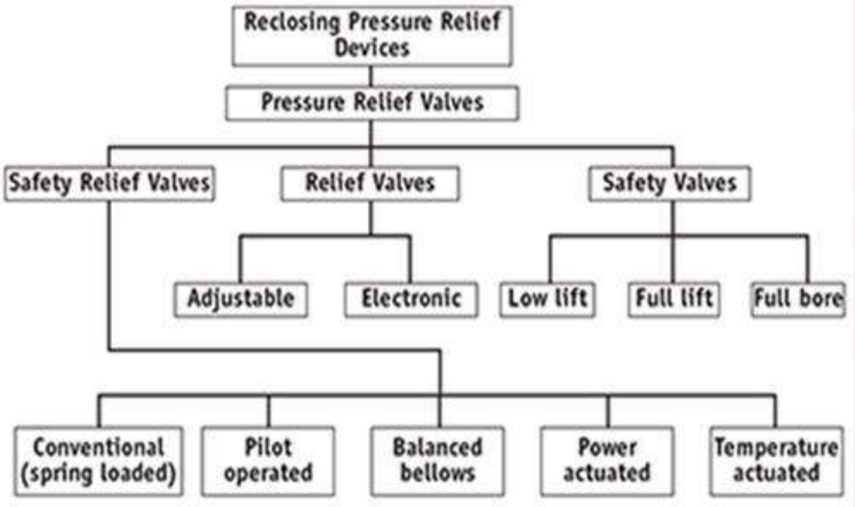
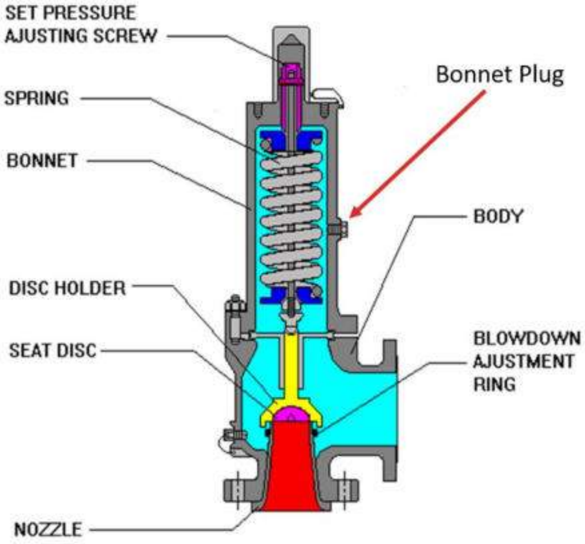

Reclosing Pressure Relief Devices
Pressure Relief Valves
Safety Relief Valves
Relief Valves
Safety Valves
Adjustable
Electronic
Low lift
Full lift
Full bore
Conventional (spring loaded)
Pilot operated
Balanced bellows
Power actuated
Temperature actuated

Figure -. Types of reclosing pressure relief devices

A **reclosing-type pressure relief device** is designed to close after operation. Types of reclosing pressure relief devices are shown in Figure. Pressure relief valves are the only category of reclosing-type devices. The primary purpose of a pressure relief valve is to open to relieve excess pressure, reclose and prevent further flow of fluid after normal conditions have been restored (Figure). A secondary purpose is to minimize damage to other system components through operation of the pressure relief valve itself. A pressure relief valve designed under ASME Boiler and Pressure Vessel Code is stamped with the certification mark, and one of the certification designators: V, NV, HV, UV, UV3 or TV.

### Pressure relief valves


SET PRESSURE
AJUSTING SCREW
Bonnet Plug
SPRING
BONNET
BODY
DISC HOLDER
SEAT DISC
BLOWDOWN
AJUSTMENT
RING
NOZZLE

**Advantages of pressure relief valves are:**

- They are reliable when properly sized and operated.
- They are versatile and can be used for many services.

**The disadvantages of pressure relief valves are:**

- The relieving pressure is affected by the back pressure (pressure that exists at the outlet of a safety relief valve).
- They are subject to chatter if built-up back pressure is too high.

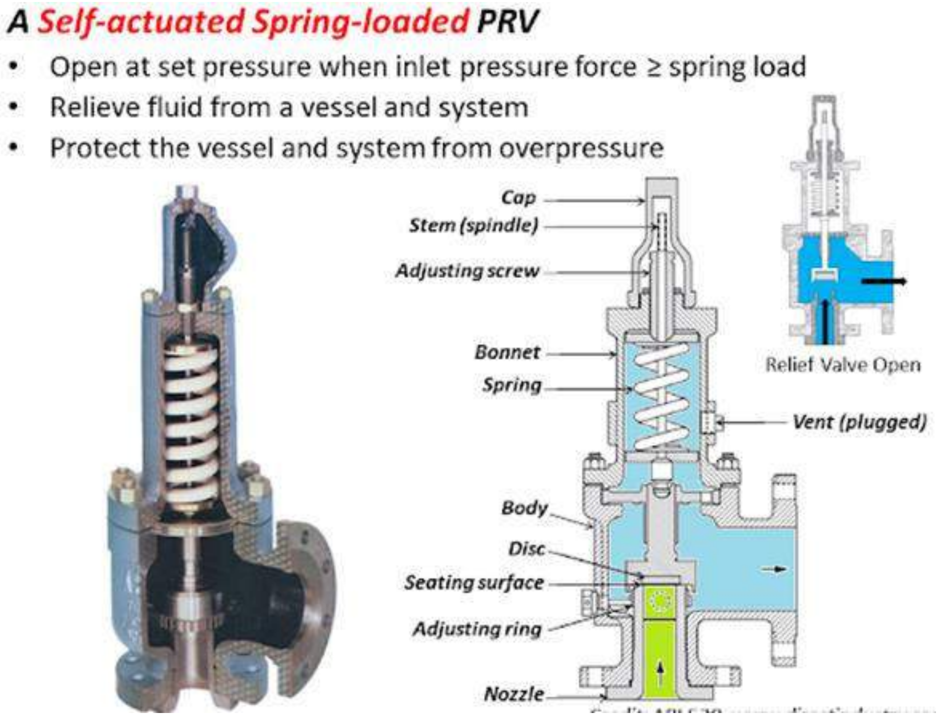
The many types of pressure relief valves that exist are based on different designs and construction. Generally, they're classified as: safety relief valves, relief valves and safety valves.

**A safety relief valve can be used for either a relief valve or a safety valve, depending on the application. Safety relief valves are classified as:**

1. Conventional safety relief valve
2. Balanced bellows
3. Pilot operated
4. Power actuated
5. Temperature and pressure actuated
6. Conventional safety relief valves

A conventional safety relief valve is a spring-loaded pressure relief valve characterized by a rapid-opening pop action. Conventional safety relief valves are used for applications where excessive variable or built-up back pressure is not present in the system. The operational characteristics of these valves are directly affected by changes in the back pressure on the valve.

## Conventional safety relief valve



**A *Self-actuated Spring-loaded* PRV**

- Open at set pressure when inlet pressure force ≥ spring load
- Relieve fluid from a vessel and system
- Protect the vessel and system from overpressure

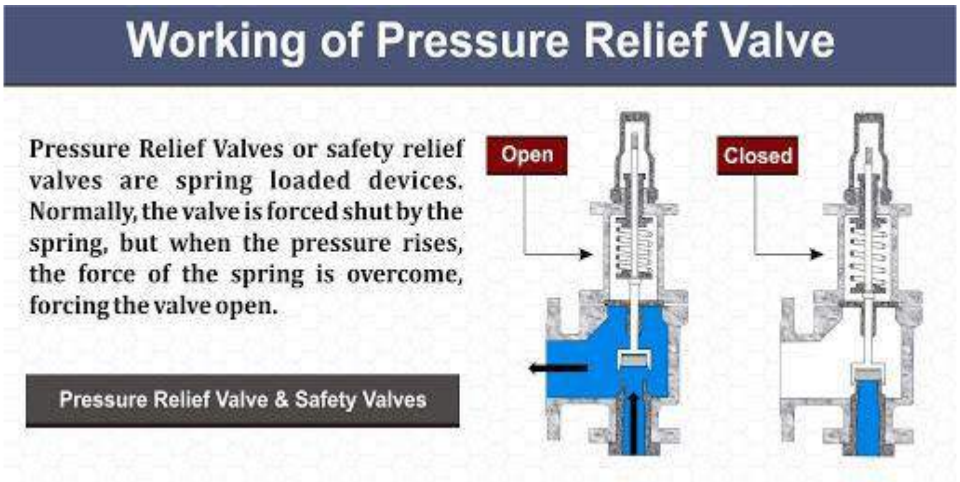
A **conventional safety relief valve** is shown in Figure.

**The basic elements of a conventional valve consist of:**

- An inlet nozzle connected to the vessel or system to be protected
- A movable disk that controls flow through the nozzle
- A spring that controls the position of the disk

The working principle of a conventional spring-loaded safety relief valve is based on the balance of force. The spring load is preset to equal the force the inlet fluid exerts on the closed disk when the system pressure is at the set pressure of the valve.

The disk remains seated on the nozzle in the closed position when the inlet pressure is below the set pressure. The valve opens when the inlet pressure exceeds set pressure, overcoming the spring force. The valve recloses when the inlet pressure is reduced to a level below the set pressure.



**Working of Pressure Relief Valve**

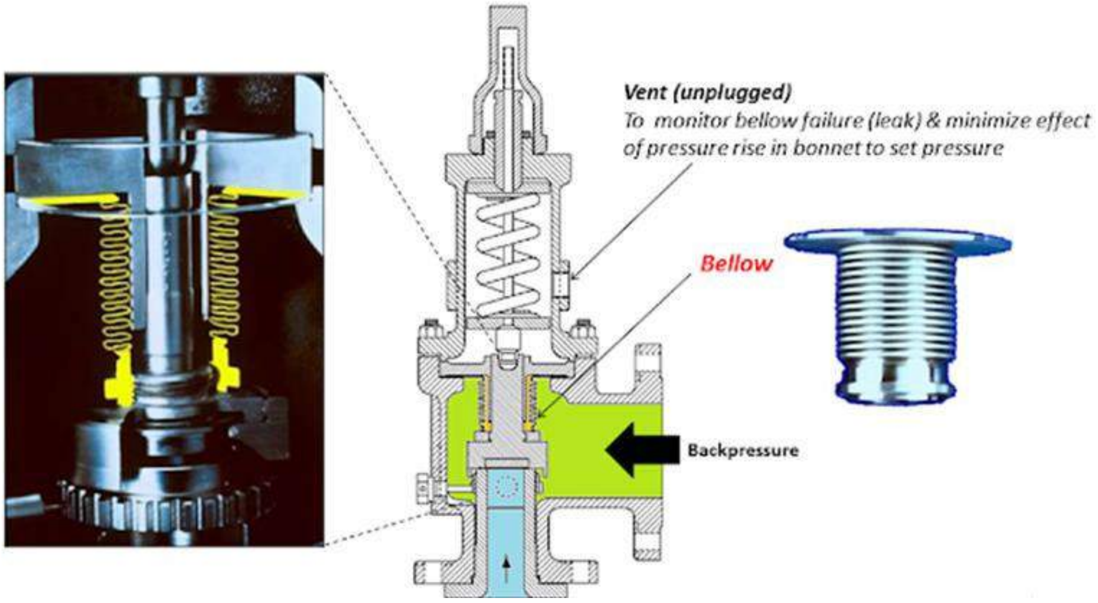
Pressure Relief Valves or safety relief valves are spring loaded devices. Normally, the valve is forced shut by the spring, but when the pressure rises, the force of the spring is overcome, forcing the valve open.

Pressure Relief Valve & Safety Valves

### Balanced bellows safety relief valve

**Conventional PRV plus a Bellow**

- Balanced bellows equalize the force of the backpressure and make unchanging set pressure and stable functioning


Vent (unplugged)
To monitor bellow failure (leak) & minimize effect of pressure rise in bonnet to set pressure
Bellow
Backpressure

A **balanced bellows safety relief valve** is a spring-loaded pressure relief valve that incorporates a bellows to minimize the effects of back pressure on the valve (Figure). The bellows offset the effects of variable back pressure, and seal process fluid from escaping to the atmosphere. They isolate the spring, bonnet and guiding surfaces from contacting process fluid.

**When back pressure is variable and exceeds 10% of the set pressure, a balanced bellows safety relief valve is recommended.**

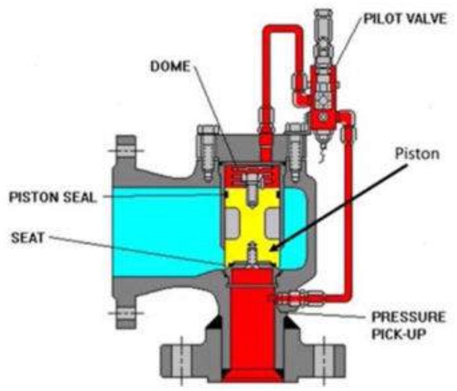
**The advantages of balanced bellows safety relief valves are:**

- The relieving pressure is not affected by the back pressure.
- They can handle higher built-up back pressure.
- They protect springs from corrosion.
- They have good chemical and high-temperature capabilities.

**Balanced bellows safety relief valves are classified into two categories:**

- Balanced bellows. This valve is the same as a conventional safety relief valve design except that a bellows has been added.
- Balanced bellows with auxiliary balancing piston. With this valve, the balanced bellows seal the body and fluid stream from the bonnet and working parts. The auxiliary balancing piston assures proper valve performance by compensating for back pressure in case the bellows fail.

### Pilot-operated safety relief valve



A **pilot-operated safety relief valve** is a pressure relief valve in which the major relieving device is combined with and controlled by a self-actuated auxiliary pressure relief (Figure).

The primary difference between a pilot-operated safety relief valve and a spring-loaded pressure relief valve is that the pilot-operated valve uses process pressure to keep the valve closed instead of a spring. A pilot is used to sense process pressure and to pressurize or vent the dome pressure chamber, which controls the valve opening or closing.

A pilot-operated safety relief valve consists of the main valve, a floating, unbalanced piston assembly, and an external pilot. The pilot controls the pressure on the top side of the main valve’s unbalanced moving chamber. A resilient seat is normally attached to the lower end.

At below-set level, the pressure on opposite sides of the moving member is equal. When the set pressure is reached, the pilot opens and depressurizes the cavity on the top side so the unbalanced member moves upward, causing the main valve to relieve. When the process pressure decreases to a predetermined pressure, the pilot closes, the cavity above the piston is depressurized and the main valve closes.

**Advantages of pilot-operated safety relief valves are:**

- The valves’ set pressure is not affected by back pressure.

- The valves operate bubble tight at higher operating pressure-to-set pressure ratios, allowing operators to run very close to the vessel's maximum allowable working pressure.
- There are reduced costs for the larger valve sizes.
- There is less susceptibility to chatter.

**Pilot-operated safety relief valves are classified as follows:**

**Based on type of moving members**

- A piston-type uses a piston for the unbalanced moving member.
- A diaphragm-type uses a flexible diaphragm to obtain a pressure seal for the dome volume instead of a piston and sliding piston seal.

**Based on type of pilots**

- A pop-action pilot causes the main valve to lift fully at set pressure without overpressure.
- A modulating-action pilot opens the main valve only enough to satisfy the required relieving capacity.

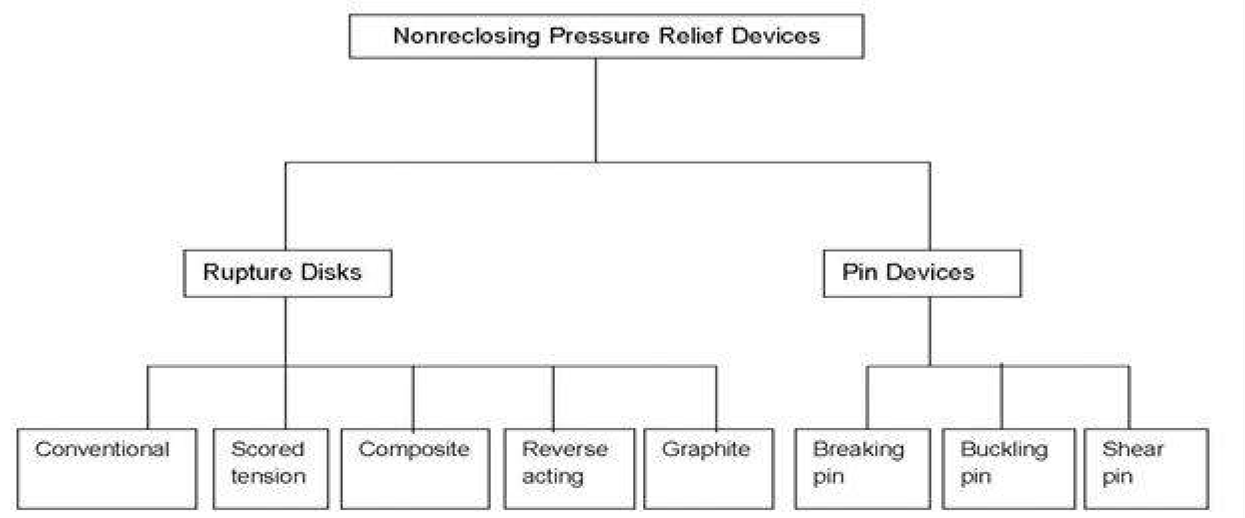
**Based on flow of pilots**

- A following-type pilot allows process fluid to flow continuously through the pilot when the pilot is open.
- A non-flowing-type pilot does not allow process fluid to flow continuously when the main valve is open.

## NONRECLOSING–TYPE PRESSURE RELIEF DEVICES

A nonreclosing-type pressure relief device is designed to remain open after operation. Generally, a manual means of resetting is provided. If it's not, the device is replaceable.

**Types of non-reclosing pressure relief devices are shown in Figure.**



## RUPTURE DISKS

A rupture disk is designed to rupture at a predetermined pressure and temperature (Figure A). If designed under ASME Boiler and Pressure Vessel Code, the rupture disks are stamped with the certification mark and one of the certification designators UD or TD.

Rupture disks are used where instantaneous and full opening of a pressure relief device is required. These devices protect vessels, piping and other pressurized systems from excessive pressure and/or vacuum.

The rupture disk is oriented with the process fluid against the concave side of the disk. As the pressure of process fluid increases beyond the allowable operating pressure, the rupture disk starts to grow. This growth continues as the pressure increases until the tensile strength of the material is reached and rupture occurs.

**Many varieties are available classified under the following categories:**

1. Conventional rupture disks
2. Scored tension rupture disks
3. Composite rupture disks
4. Reverse acting rupture disks
5. Graphite rupture disks

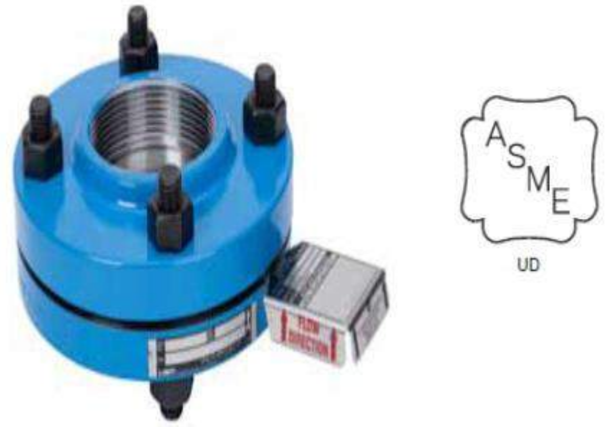


Figure A. A rupture disk between two flanges

## CONVENTIONAL RUPTURE DISKS

A conventional rupture disk is a prebulged solid metal disk designed to burst when overpressure on the concave side (Figure B). After bursting, the domed rupture disk fragments.

This type of disk with a flat or an angular seat provides satisfactory service if operating pressure is 70% or less of the rated burst pressure and when limited pressure cycling and temperature changes are present. **The main advantages of this type of rupture disks are:**

- There are a broad range of applications for gas and liquids.
- They are available in various sizes, burst pressures, temperatures and materials.
- The working principle behind the conventional rupture disk is that it has no moving parts, and it is a simple, reliable, full-opening and faster-acting device than other pressure relief devices.

**The rupture disk assembly is comprised of two parts:**

- The disk, which is the thin, metal diaphragm bulged to a spherical shape to provide both a consistent burst pressure within a predictable tolerance and an extended service life, and
- A rupture disk holder, which is a flanged structure designed to hold the rupture disk in position. The disk may have a flat seat or a 30o angle seat.

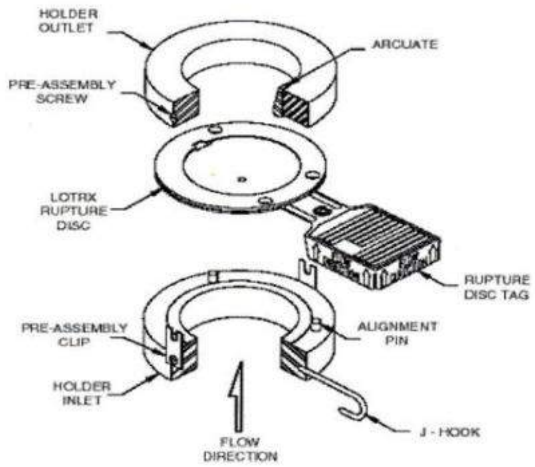


Figure B. Conventional rupture disk

## SCORED TENSION-LOADED RUPTURE DISKS

A scored tension-loaded rupture disk is designed to open along scored lines (Figure C). Because the score lines control the opening pattern, this type of disk is generally nonfragmenting. It allows up to 85% operating pressure to disk burst pressure.

**The main advantages of the scored tension loaded rupture disks are:**

- They are nonfragmenting.
- Vacuum support is not required.
- There are a broad range of applications.
- They are available in various sizes, burst pressures and materials.

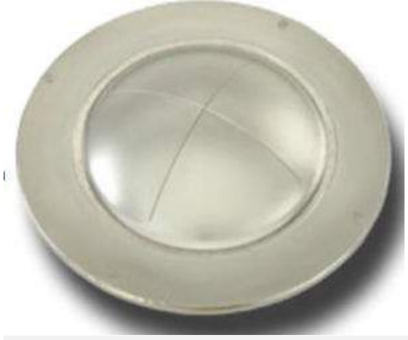


Figure C. Forward-acting scored rupture disk

## COMPOSITE RUPTURE DISKS

A composite rupture disk is a flat or domed metallic or non-metallic multi-piece construction disk (Figure D). The domed construction disk is designed to burst when overpressurized on the concave side. The flat composite disk is designed to burst when over pressurized on the side the manufacturer designs. **The main advantage of composite rupture disks are:**

- The disks allow use of corrosion-resistant materials in lower pressure service.
- They are smaller in size than solid metal disks.
- Generally, they have advantages similar to those of conventional rupture disks.

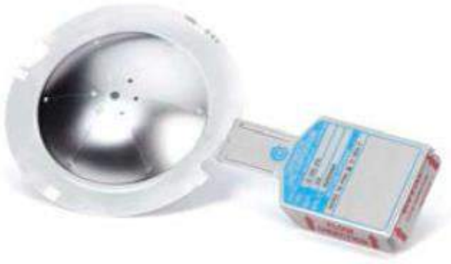


Figure D. Composite rupture disk

## REVERSE-ACTING RUPTURE DISKS

A reverse-acting rupture disk is a domed solid metal disk designed to burst when over pressurized on the convex side (Figure E). As the burst pressure rating is reached, the compression loading on the rupture disk causes it to reverse, snapping through the neutral position and causing it to open by a predetermined scoring pattern or knife-blade penetration.

Reverse-acting rupture disks open by various methods, such as shears, knife blades, knife rings or scored lines. **The main advantages of the reverse-acting rupture disks are:**

- The disks can be operated to 95% of stamped burst pressure.
- They have longer service life under cyclic or pulsating conditions.
- They are constructed using thicker materials, providing greater resistance to corrosion.
- They are available in a wide ranges of sizes, materials, pressures and temperatures.

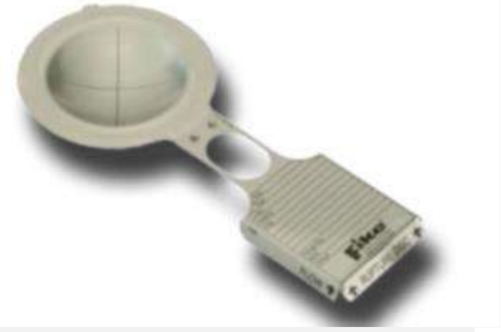


Figure E. Reverse-acting rupture disk

## GRAPHITE RUPTURE DISKS

A graphite rupture disk is manufactured from graphite impregnated with binder material. It is designed to burst by bending or shearing (Figure F). Graphite rupture disks are resistant to most acids, alkalis and organic solvents.

Graphite rupture disks are classified as mono-type, duplex-type, inverted-type and two-way type disks. **The main advantages of graphite rupture disks are:**

- They offer ultra-low rated pressure settings.
- They can be used for highly corrosive fluids.
- They eliminate back pressure effects on overpressure devices in common vent lines.
- They are easy to install and maintain.

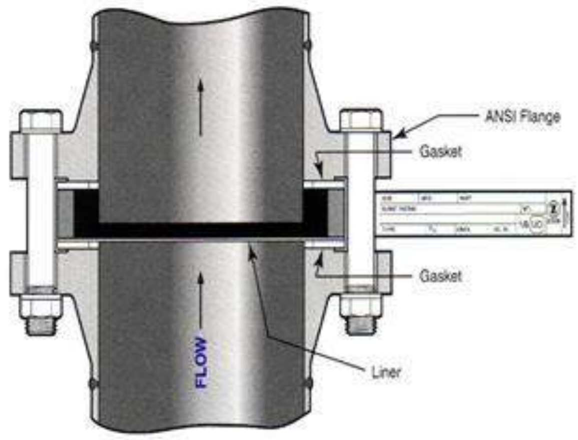


Figure F. Graphite rupture disk – duplex type

## RUPTURE DISK ACCESSORIES

Though rupture disks are simple pressure relief devices, some accessories make them more useful such as:

- When connected to an electric alarm, a burst sensor is used to alert an operator when a rupture disk bursts. Once bursting of the disk is known, the operator can take immediate action to protect the pressure relief valve from further damage.
- An alarm system with an alarm monitor uses a normally closed electrical circuit. When the disk ruptures, it breaks the circuit triggering the alarm. If used in conjunction with a burst sensor, it immediately alerts an operator of a ruptured disk.
- Heat shields are installed upstream of the rupture disk in high-process-temperature applications to reduce the temperature at the rupture disk.
- Baffle plates are used to deflect process discharge away from personnel and equipment. These are effective when rupture disks are venting to atmosphere.

## PIN DEVICES

A second type of non-reclosing pressure relief device is a pin device, which functions similar to rupture disks. A pin device is actuated by static differential pressure or static inlet pressure. They are designed to function by the activation of a load bearing section of a pin that supports a pressure containing member (Figure G). If designed under ASME Boiler and Pressure Vessel Code, the pin devices are stamped with the certification mark, and one of the certification designators UD or TD.

A pin is the load-bearing element of the device. Pin device housing encloses the pressure-containing members.

Pin devices are often used in applications where rupture disks must be replaced because of frequent failures. Replacing rupture disks with pin devices allows pressure running slightly closer to design pressure which can mean a capacity increase.

**Types of pin devices are available classified under the following categories:**

1. Breaking pin device
2. Buckling pin device
3. Shear pin device

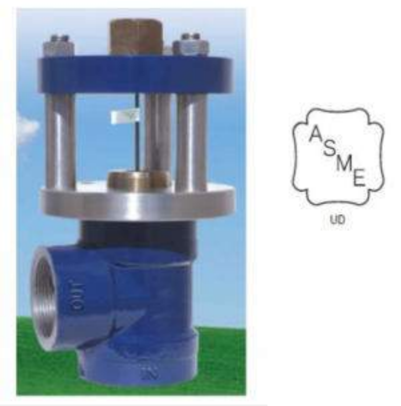


Figure G. Pin device

## BREAKING PIN DEVICES

A breaking pin (also called rupture pin) device is actuated by inlet static pressure (Figure H). The device is designed to function by breaking a load-carrying section of a pin that supports a pressure-containing member. An O-ring on the piston is used to make a bubble-tight seal.

**The main advantages of breaking pin devices are:**

- They are not subjected to premature failure from fatigue.
- They are suitable for operating closer to set point.
- They are suitable for operating as low as 0.1 psi.
- When installed under a pressure relief valve, a breaking pin device can be reset without removing the pressure relief valve.

The working principle is that a breaking pin device usually consists of a piston on a seat, retrained from movement to the open position by a slender round pin. The pin buckles at set point from an axial force caused by the system pressure acting on the piston area. The buckling point of the pin is determined by the unrestrained pin length, the pin diameter and the modulus of elasticity of the pin material. The breaking pin device can be designed to sense system pressure only, or differential pressure only. The device can have a set pressure from 0.1 to 35,000 psi.

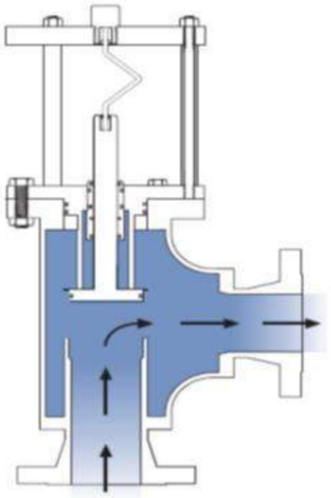


Figure H. Breaking pin device

## BUCKLING PIN DEVICES

A buckling pin device provides quick and simple rest without removing the device from the pressurized system (Figure I). The device is designed to function by the buckling of an axially loaded compressive pin that supports a pressure-containing member.

The buckling pin device has **three primary components**: a rotating disk, a flanged body and an external enclosure and mechanism. When an external load is applied to a straight cylindrical pin, it buckles at a specific load. **The main advantages of the buckling pin devices are:**

- The set pressure remains unaffected by the cycling/pulsating pressure.
- They have easy external settings.
- The buckling pin is totally protected with a rugged enclosure.
- They can be used up to 95% of the set pressure.

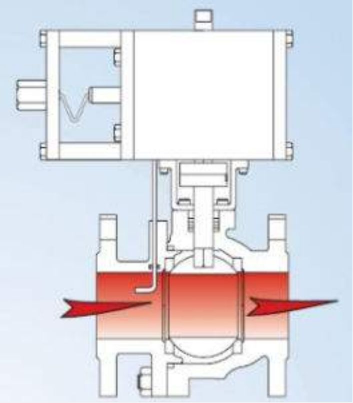


Figure I. Bucking pin device

### SHEAR PIN DEVICES

A shear pin device is actuated by inlet static pressure. The device is designed to function by the shearing of a load-carrying pin that supports a pressure-containing member. The force of overpressure forces the pin to buckle and the device to open. The device can be reseated after the pressure is removed and a new pin can be installed.

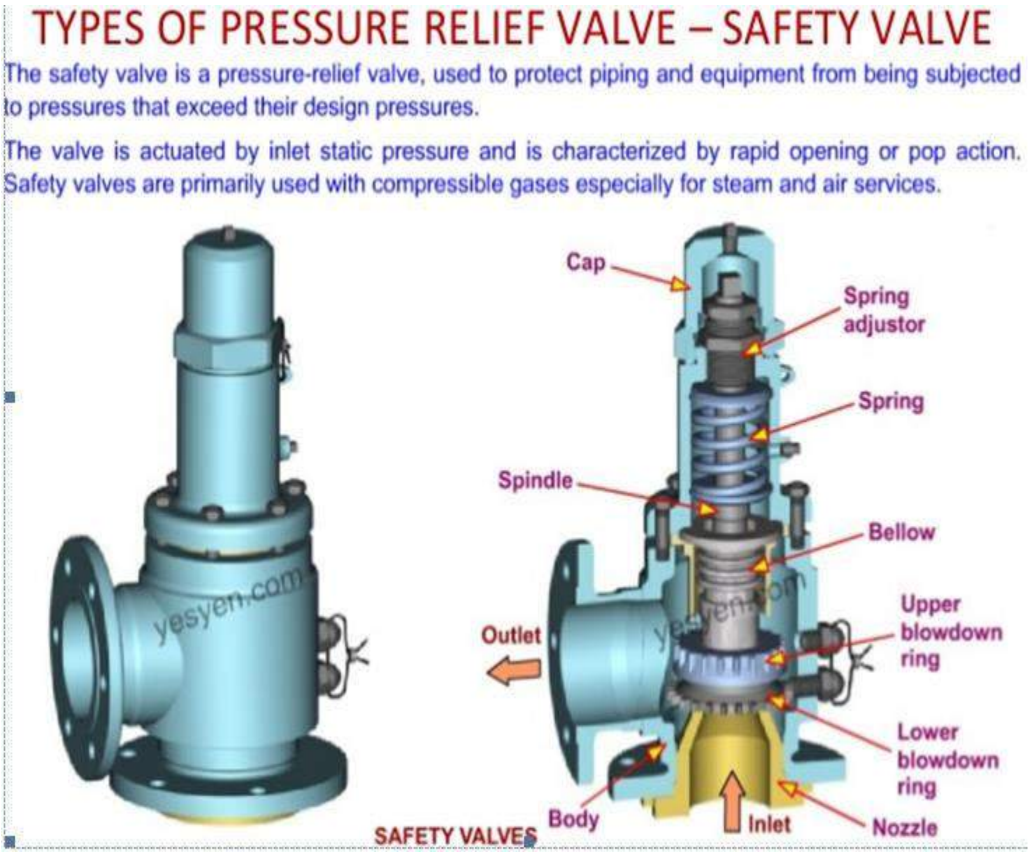
### PIN DEVICE ACCESSORIE

**Pin device accessories include**:

- The proximity device senses piston opening and gives a remote warning of opening.
- The remote operation mechanism allows a pin device under pressure to open or close by the force from an energized solenoid coil. A remote signal can energize the solenoid.
- A pressure balancing piston is used so that containment pressure does not affect set point. As a result exact set point is maintained.

- **What is the difference between safety valve and relief valve?**

The safety valve is the value which will work both in high pressure & low pressure situation. (It will work irrespective of pressures difference).Whereas the relief valve will work only when the pressure is high. In order to bring the required stability pressure Relief valve will allow the excess pressure to come out above certain limit and when the pressure drops valve will automatically close. But in case of safety valve when the pressure exceed the set limit will release the total pressure means valve will open until the pressure goes to zero...



TYPES OF PRESSURE RELIEF VALVE – SAFETY VALVE

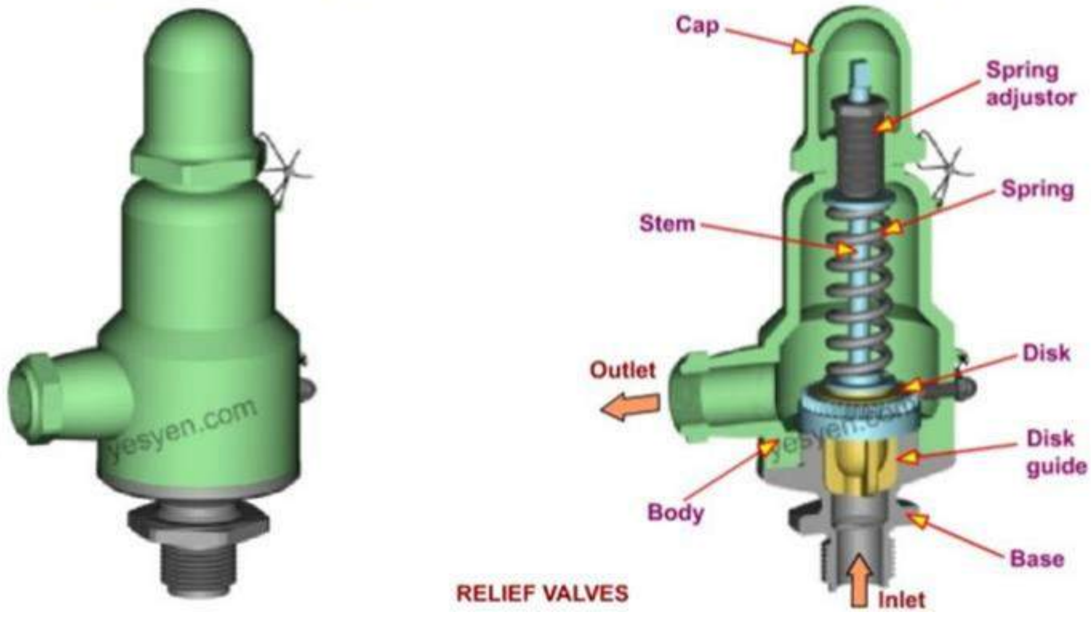
The safety valve is a pressure-relief valve, used to protect piping and equipment from being subjected to pressures that exceed their design pressures.

The valve is actuated by inlet static pressure and is characterized by rapid opening or pop action. Safety valves are primarily used with compressible gases especially for steam and air services.

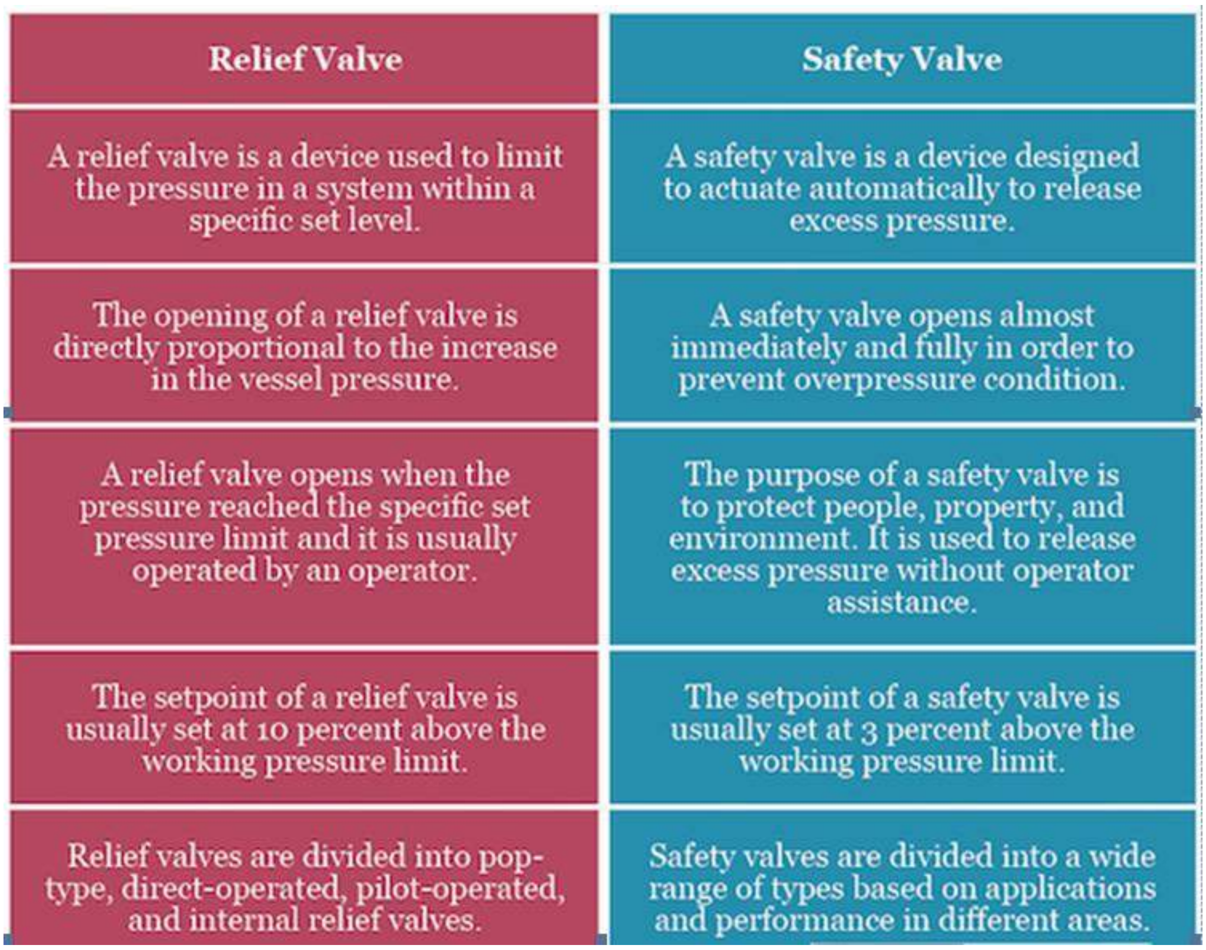
# TYPES OF PRESSURE RELIEF VALVE – RELIEF VALVE

The relief valve is a pressure-relief device, used to protect piping and equipment from being subjected to pressures that exceed their design pressures.

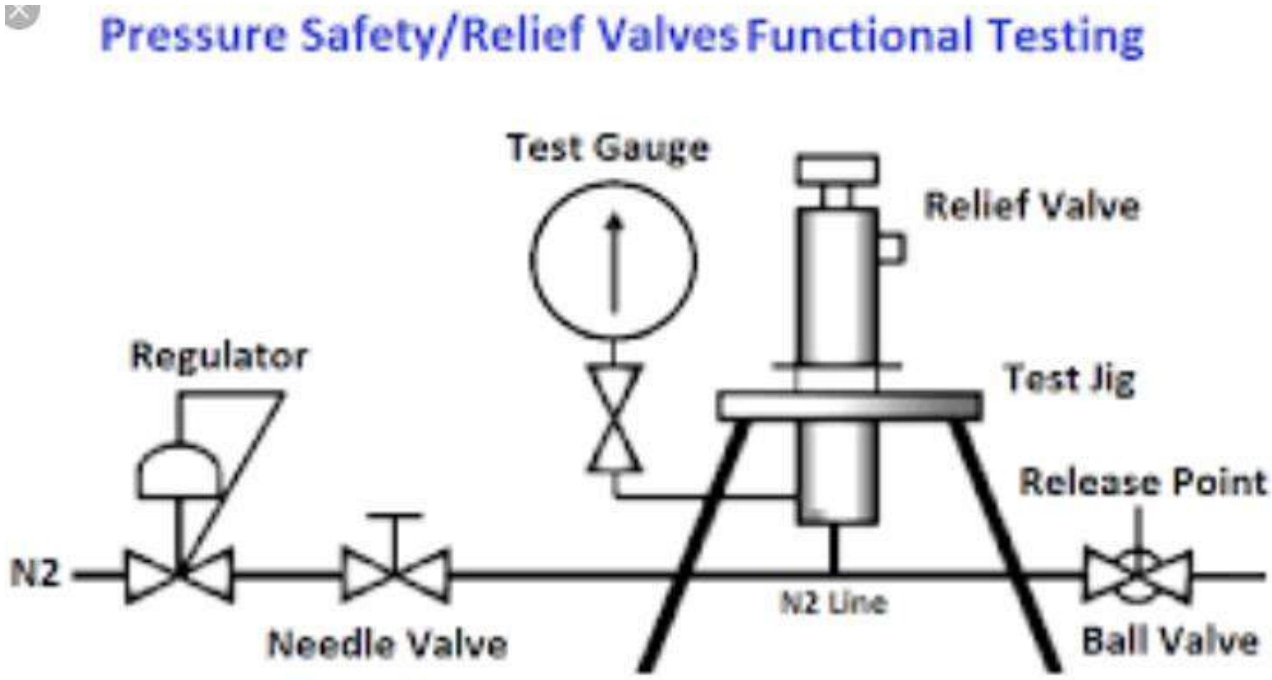
The valve is a actuated by inlet static pressure, having a gradual lift generally proportional to the increase in pressure over opening pressure. Relief valves are commonly used in liquid systems.



RELIEF VALVES



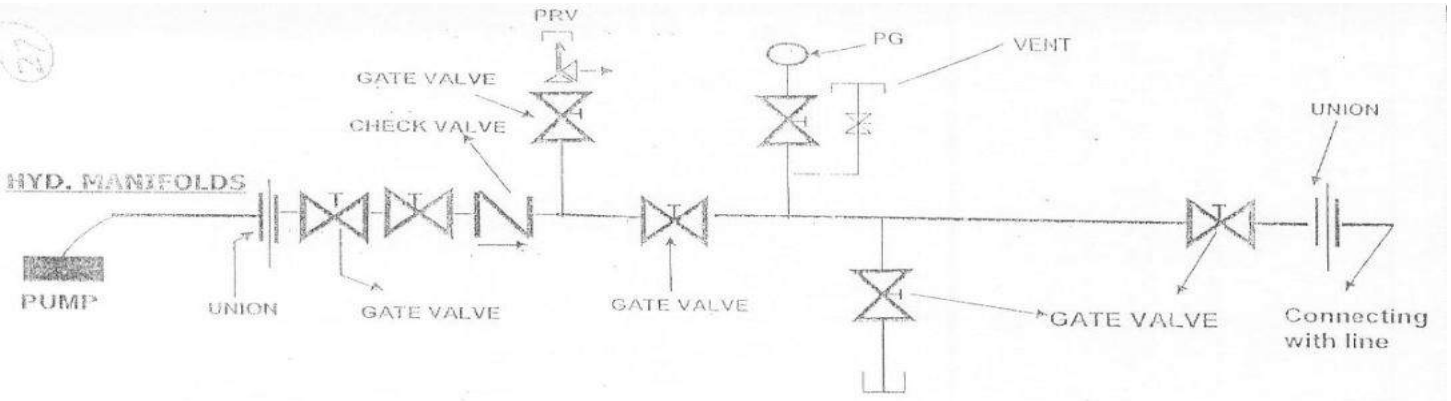
| Relief Valve | Safety Valve |
|---|---|
| A relief valve is a device used to limit the pressure in a system within a specific set level. | A safety valve is a device designed to actuate automatically to release excess pressure. |
| The opening of a relief valve is directly proportional to the increase in the vessel pressure. | A safety valve opens almost immediately and fully in order to prevent overpressure condition. |
| A relief valve opens when the pressure reached the specific set pressure limit and it is usually operated by an operator. | The purpose of a safety valve is to protect people, property, and environment. It is used to release excess pressure without operator assistance. |
| The setpoint of a relief valve is usually set at 10 percent above the working pressure limit. | The setpoint of a safety valve is usually set at 3 percent above the working pressure limit. |
| Relief valves are divided into pop-type, direct-operated, pilot-operated, and internal relief valves. | Safety valves are divided into a wide range of types based on applications and performance in different areas. |



Pressure Safety/Relief Valves Functional Testing

Test Gauge
Relief Valve
Regulator
Test Jig
Release Point
N2
N2 Line
Needle Valve
Ball Valve

**HYDRO TEST MANIFOLD**:



PRV
PG
VENT
GATE VALVE
CHECK VALVE
UNION
HYD. MANIFOLDS
PUMP
UNION
GATE VALVE
GATE VALVE
GATE VALVE
Connecting with line

| | |
|---|---|
| ➤ HYD. TEST PUMP | - 1No. |
| ➤ UNION | - 2No. |
| ➤ CHECK VALVE | - 1No. |
| ➤ GATE VALVE | - 8No. |
| ➤ END CAP | - 1No. |
| ➤ PRV | - 1No. |
| ➤ PRESSURE GUAGE | - 2No. ( 1 IN MANIFOLD AND 1 IN CONCERN LINE ) |

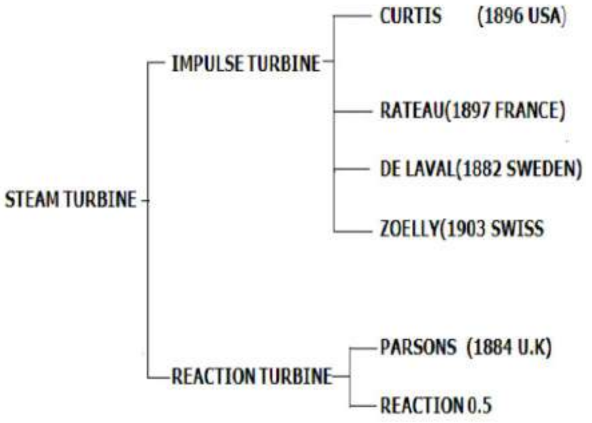
# TURBINE:

A **turbine** is a rotary mechanical device that extracts energy from a fast moving flow of water, steam, gas, air, or other fluid and converts it into useful work. A turbine is a turbo-machine with at least one moving part called a rotor assembly, which is a shaft or drum with blades attached. Moving fluid acts on the blades so that they move and impart rotational energy to the rotor.

**Basic types of TURBINES**: Water Turbine , Steam Turbine , Gas Turbine , Wind Turbine although the same principles apply to all turbines.

**Working Principle** • When the fluid strikes on the blades of the turbine, the blades are displaced, which produces rotational energy , When the turbine shaft is directly coupled to an electric generator mechanical energy is converted into electrical energy.

| **Head Classification** | **Turbine Type** | | |
|---|---|---|---|
| | *Impulse* | *Reaction* | *Gravity* |
| High (>50m) | • Pelton<br>• Turgo | | |
| Medium (10-50m) | • Crossflow<br>• Turgo<br>• Multi-jet Pelton | • Francis (spiral case) | |
| Low (<10m) | • Crossflow<br>• Undershot waterwheel | • Propeller<br>• Kaplan<br>• Francis (open-flume) | • Overshot waterwheel<br>• Archimedes Screw |

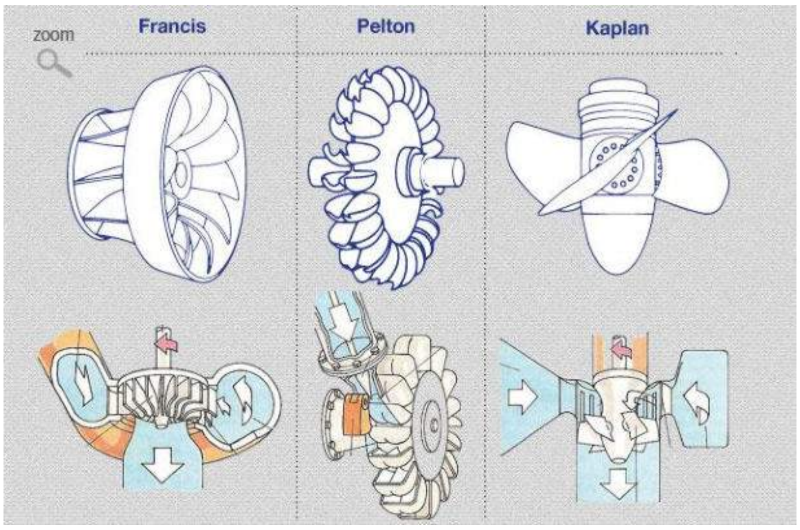


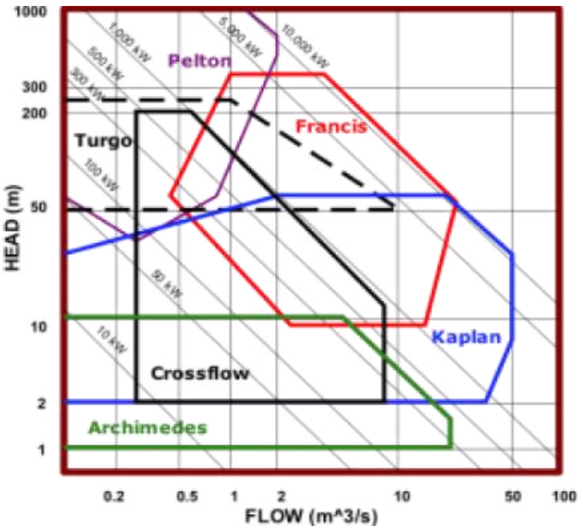
- **Impulse Turbines**

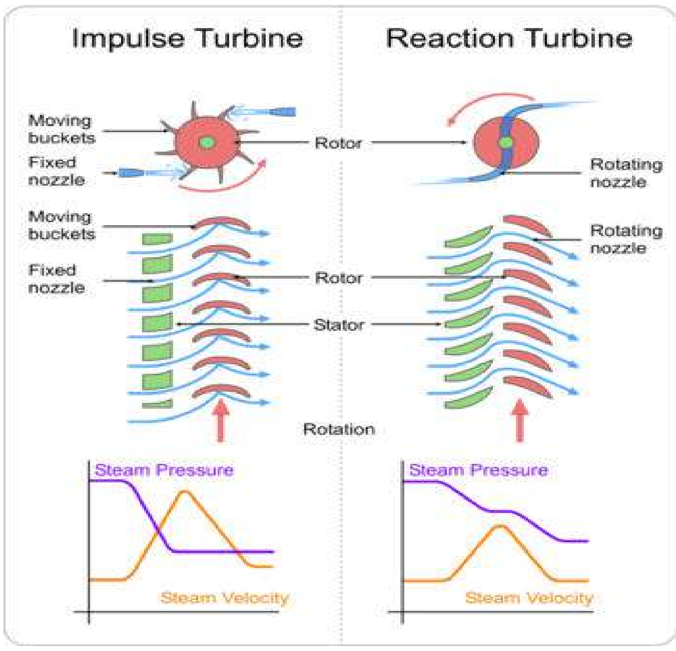
  The steam jets are directed at the turbine's bucket shaped rotor blades where the pressure exerted by the jets causes the rotor to rotate and the velocity of the steam to reduce as it imparts its kinetic energy to the blades. The blades in turn change the direction of flow of the steam however its pressure remains constant as it passes through the rotor blades since the cross section of the chamber between the blades is constant. Impulse turbines are therefore also known as constant pressure turbines. The next series of fixed blades reverses the direction of the steam before it passes to the second row of moving blades.

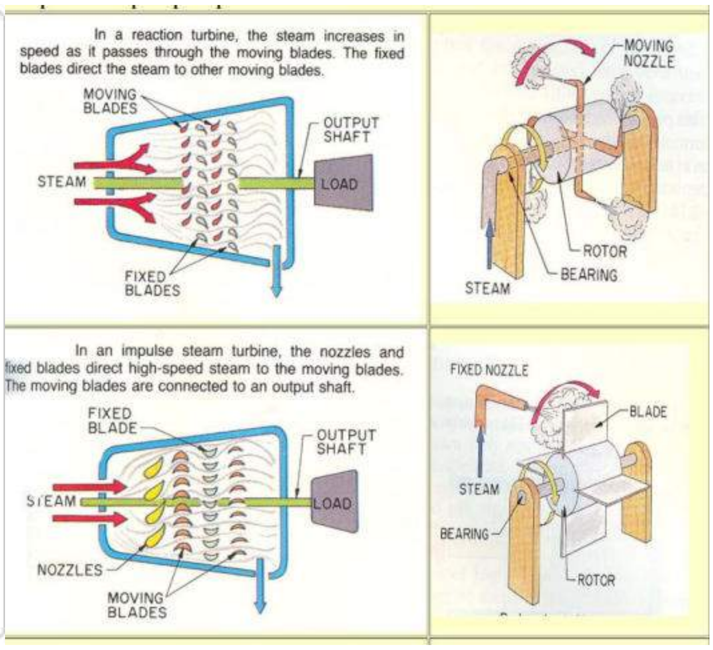
- **Reaction Turbines**

  The rotor blades of the reaction turbine are shaped more like aerofoil’s, arranged such that the cross section of the chambers formed between the fixed blades diminishes from the inlet side towards the exhaust side of the blades. The chambers between the rotor blades essentially form nozzles so that as the steam progresses through the chambers its velocity increases while at the same time its pressure decreases, just as in the nozzles formed by the fixed blades. Thus the pressure decreases in both the fixed and moving blades. As the steam emerges in a jet from between the rotor blades, it creates a reactive force on the blades which in turn creates the turning moment on the turbine rotor, (Newton's Third Law - For every action there is an equal and opposite reaction)






Impulse Turbine
Reaction Turbine
Moving buckets
Fixed nozzle
Rotor
Rotating nozzle
Moving buckets
Fixed nozzle
Rotor
Stator
Rotating nozzle
Rotation
Steam Pressure
Steam Velocity
Steam Pressure
Steam Velocity

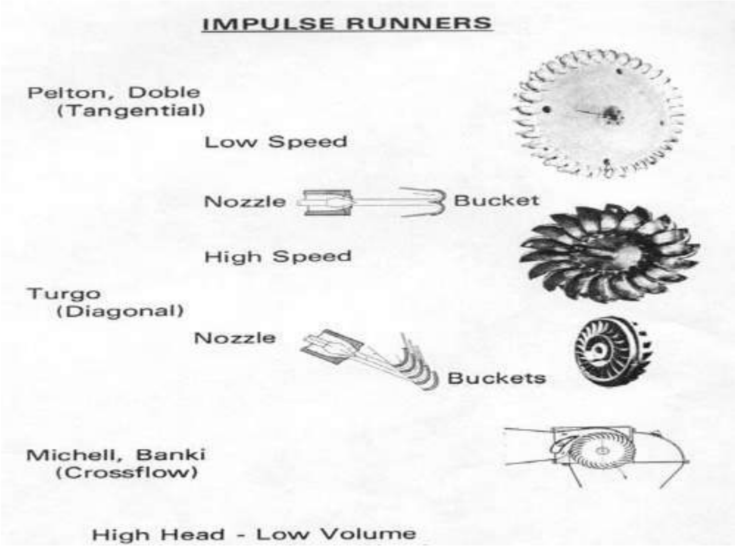

In a reaction turbine, the steam increases in speed as it passes through the moving blades. The fixed blades direct the steam to other moving blades.

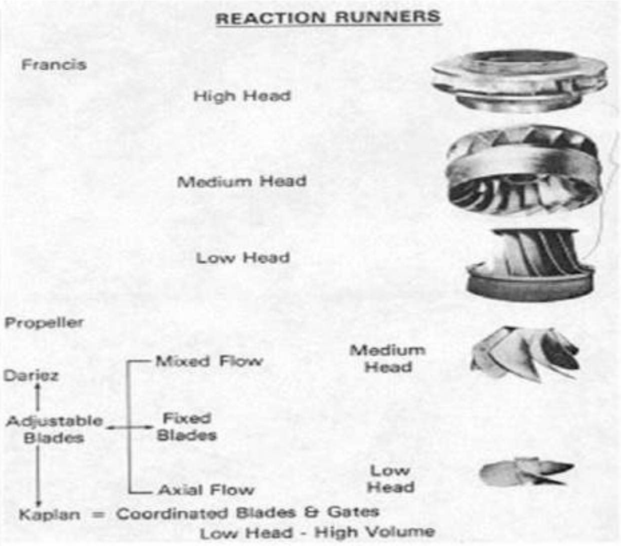
MOVING BLADES
OUTPUT SHAFT
STEAM
LOAD
FIXED BLADES
MOVING NOZZLE
ROTOR
BEARING
STEAM

In an impulse steam turbine, the nozzles and fixed blades direct high-speed steam to the moving blades. The moving blades are connected to an output shaft.

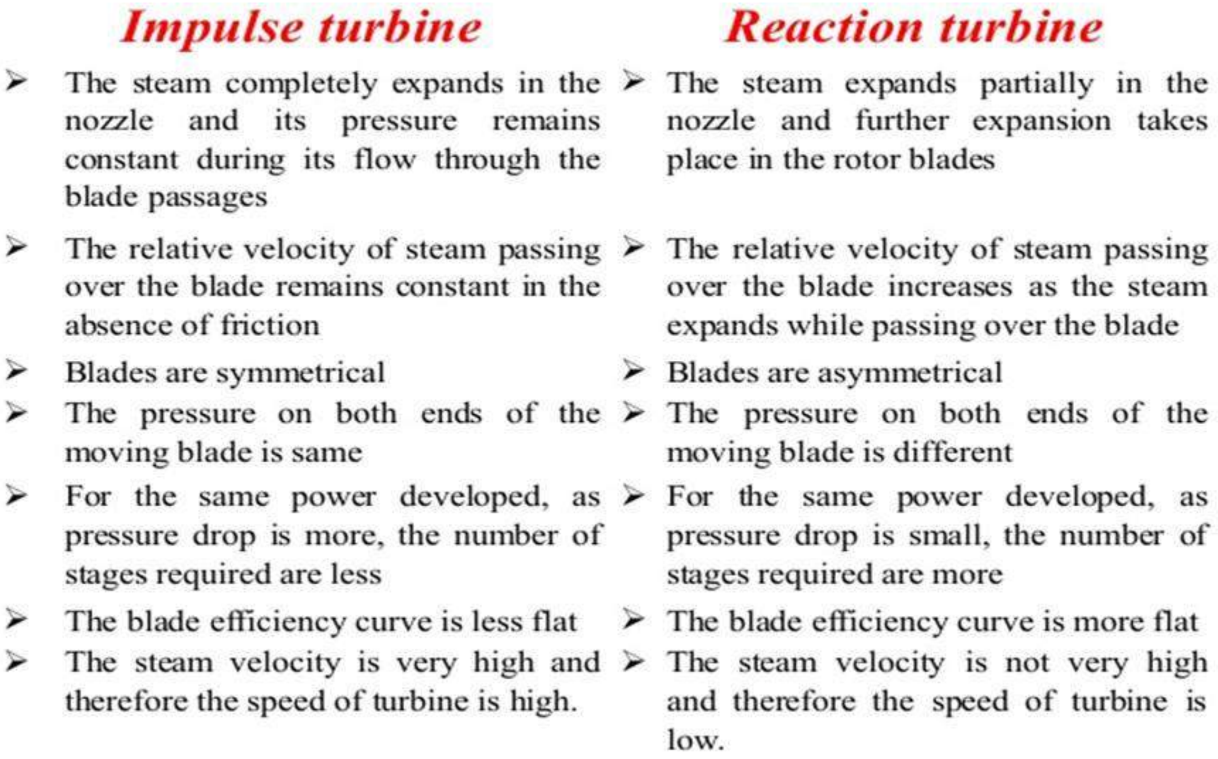
FIXED BLADE
OUTPUT SHAFT
STEAM
LOAD
NOZZLES
MOVING BLADES
FIXED NOZZLE
BLADE
STEAM
BEARING
ROTOR

## Types of turbine runner :

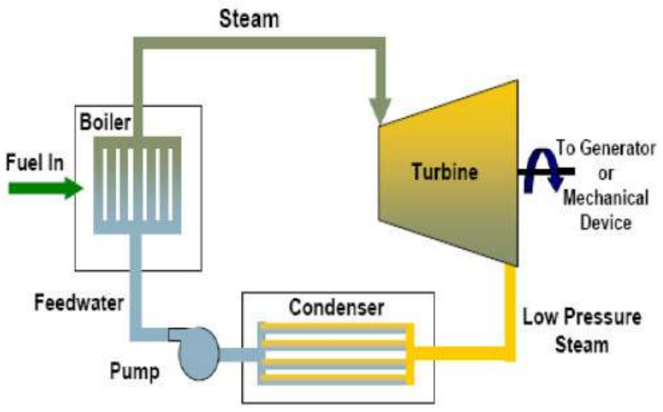

IMPULSE RUNNERS
Pelton, Doble
(Tangential)
Low Speed
Nozzle
Bucket
High Speed
Turgo
(Diagonal)
Nozzle
Buckets
Michell, Banki
(Crossflow)
High Head - Low Volume


REACTION RUNNERS
Francis
High Head
Medium Head
Low Head
Propeller
Dariez
Adjustable Blades
Mixed Flow
Fixed Blades
Axial Flow
Medium Head
Low Head
Kaplan = Coordinated Blades & Gates
Low Head - High Volume

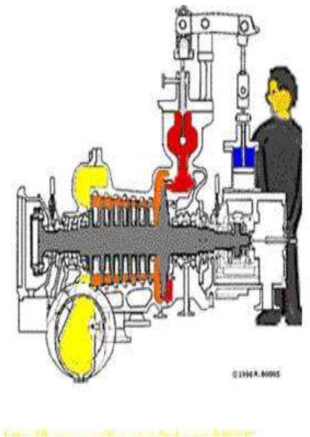
## Difference between impulse and reaction turbine :



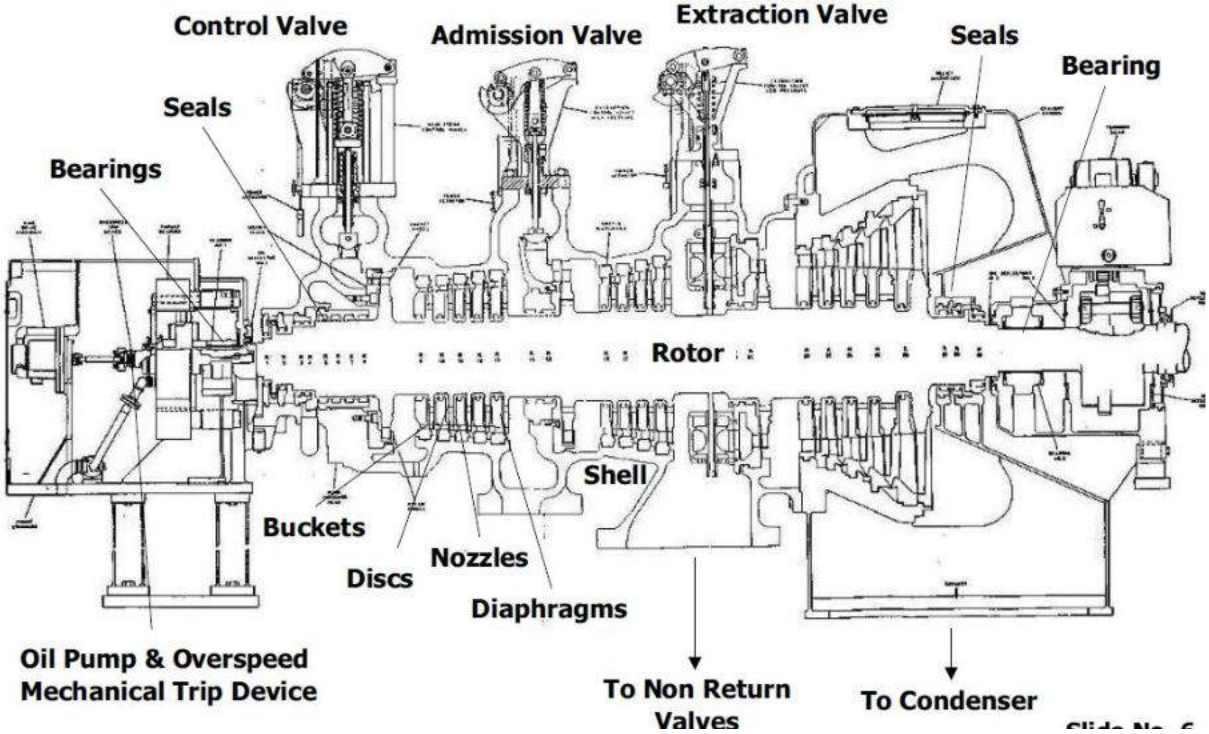
| *Impulse turbine* | *Reaction turbine* |
|---|---|
| ➢ The steam completely expands in the nozzle and its pressure remains constant during its flow through the blade passages | ➢ The steam expands partially in the nozzle and further expansion takes place in the rotor blades |
| ➢ The relative velocity of steam passing over the blade remains constant in the absence of friction | ➢ The relative velocity of steam passing over the blade increases as the steam expands while passing over the blade |
| ➢ Blades are symmetrical | ➢ Blades are asymmetrical |
| ➢ The pressure on both ends of the moving blade is same | ➢ The pressure on both ends of the moving blade is different |
| ➢ For the same power developed, as pressure drop is more, the number of stages required are less | ➢ For the same power developed, as pressure drop is small, the number of stages required are more |
| ➢ The blade efficiency curve is less flat | ➢ The blade efficiency curve is more flat |
| ➢ The steam velocity is very high and therefore the speed of turbine is high. | ➢ The steam velocity is not very high and therefore the speed of turbine is low. |

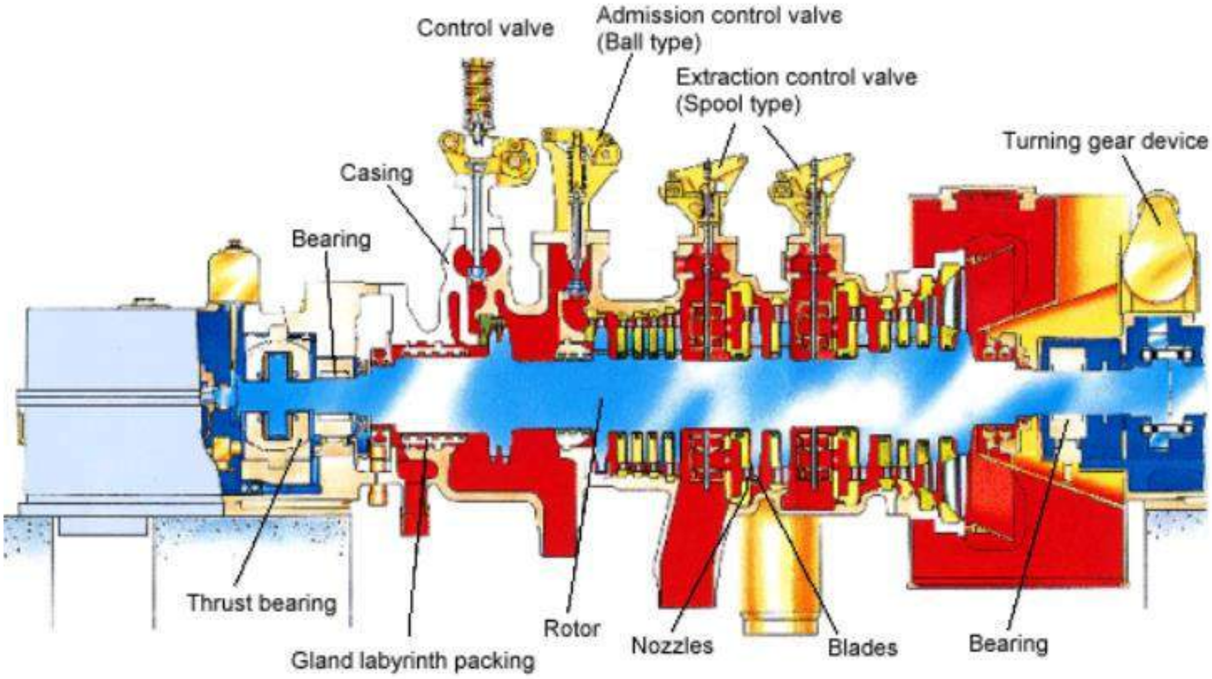

Steam
Boiler
Fuel In
Turbine
To Generator or Mechanical Device
Feedwater
Condenser
Pump
Low Pressure Steam

- High Pressure Steam expands through a governor valve and a nozzle.
- Experiences an increase in velocity and momentum
- Pushes the impeller to drive the turbine.



## Steam Turbine Component Characteristics and Mechanisms

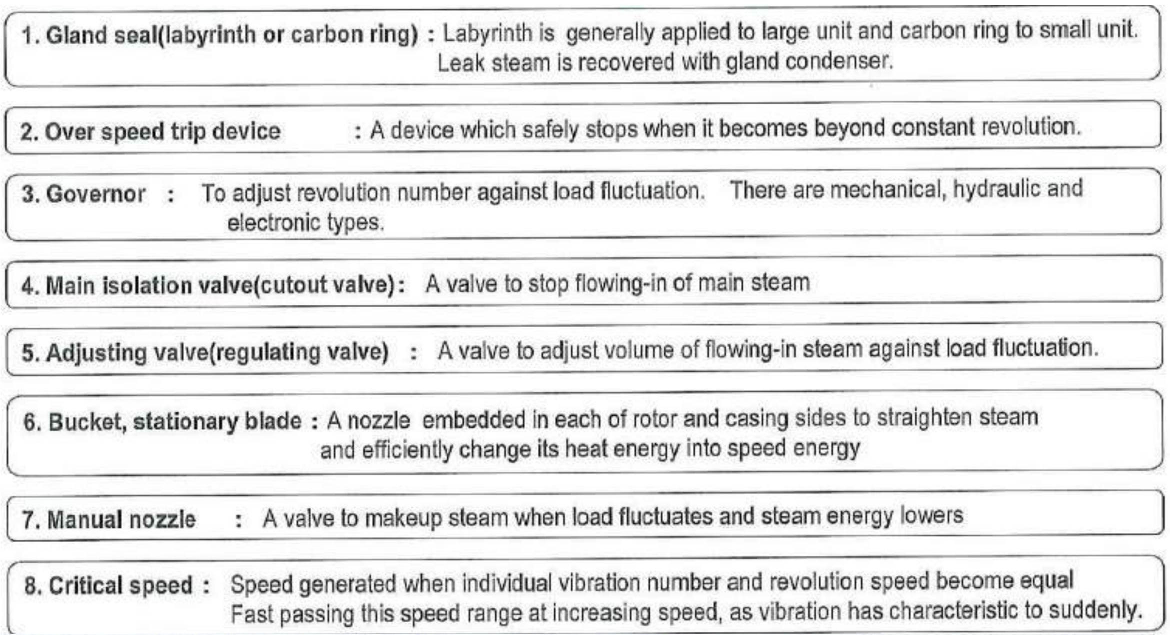

Control Valve
Admission Valve
Extraction Valve
Seals
Bearing
Seals
Bearings
Rotor
Shell
Buckets
Nozzles
Discs
Diaphragms
Oil Pump & Overspeed Mechanical Trip Device
To Non Return Valves
To Condenser


Control valve
Admission control valve (Ball type)
Extraction control valve (Spool type)
Turning gear device
Casing
Bearing
Thrust bearing
Gland labyrinth packing
Rotor
Nozzles
Blades
Bearing

## Steam Turbine Blading

Steam turbines produce power by converting the energy in steam provided from a boiler or heat recovery steam generator (HRSG) into rotational energy as the steam passes through a turbine stage. A turbine stage normally consists of a row of stationary blading and a row of rotating blading. **The purpose of the stationary blading is to direct the flow of the passing steam to the rotating blading at the proper angle and velocity for the highest efficiency and extraction of power. The purpose of the rotating blading is to convert the directed mass flow and steam velocity into rotational speed and torque.** Stationary blading may be referred to as nozzles, vanes, stators, partitions, and stationary blading while rotating blades may be referred to as buckets, blades, and rotating blading. A turbine may have a single row or stage of stationary and rotating blading or may have multiple rows or stages of blading. Steam turbine blading have different shapes which are referred to as either impulse blading or reaction blading. Impulse blading is characterized by high velocity fluids entering the turbine blade, by a blade profile that efficiently turns the direction of the fluid with little pressure change, and by decreasing the velocity of the fluid as it leaves the blade to extract energy. Typical **impulse blades** are crescent or U-shaped and may not always be symmetrical. **Reaction blading** is characterized by high velocity fluids entering the turbine blade, but not as high as impulse velocity levels, by a blade profile that efficiently allows the fluid to expand while passing through the blade, and by decreasing both the velocity and pressure of the fluid as it exits from the blade to extract energy. Typical reaction blading has tear-drop shaped leading edges with a tapered thickness to the trailing edge. The blades may have twist to their shape which may range from low amounts of twist or reaction at the base of the blade to high twist or reaction at the tip of the blade. **Impulse type blading** is typically utilized in the high pressure or front sections of the steam turbine while **reaction blading** is utilized in the lower pressure or behind sections of the turbine.

## TURBINE PARTS AND FUNCTION



**1. Gland seal(labyrinth or carbon ring) :** Labyrinth is generally applied to large unit and carbon ring to small unit. Leak steam is recovered with gland condenser.

**2. Over speed trip device** : A device which safely stops when it becomes beyond constant revolution.

**3. Governor** : To adjust revolution number against load fluctuation. There are mechanical, hydraulic and electronic types.

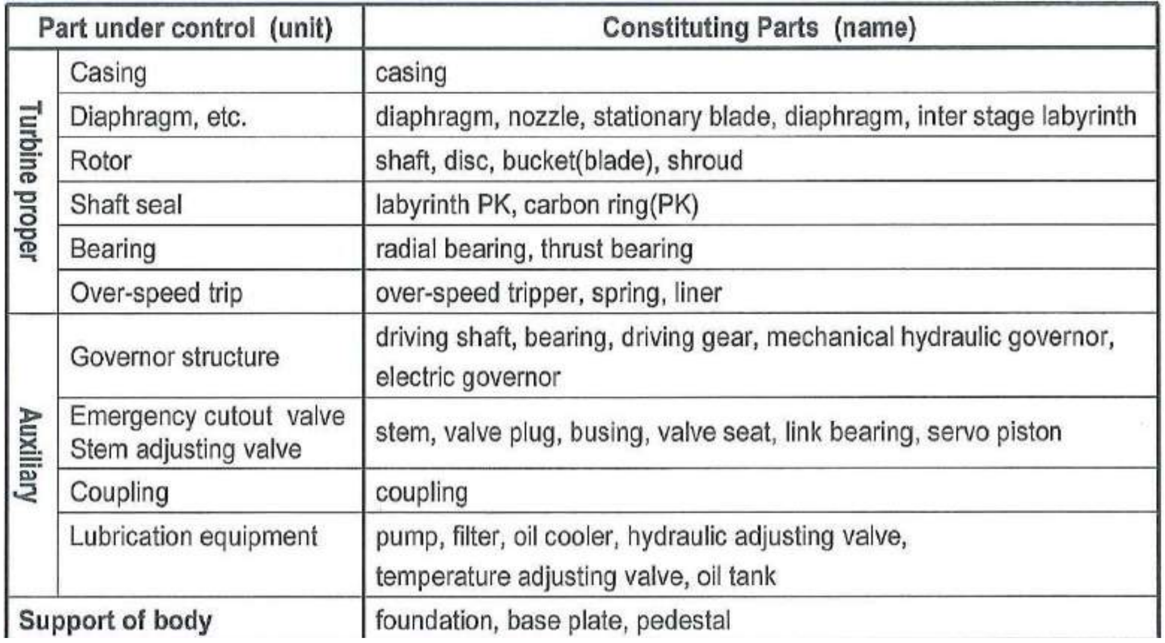
**4. Main isolation valve(cutout valve) :** A valve to stop flowing-in of main steam

**5. Adjusting valve(regulating valve)** : A valve to adjust volume of flowing-in steam against load fluctuation.

**6. Bucket, stationary blade :** A nozzle embedded in each of rotor and casing sides to straighten steam and efficiently change its heat energy into speed energy

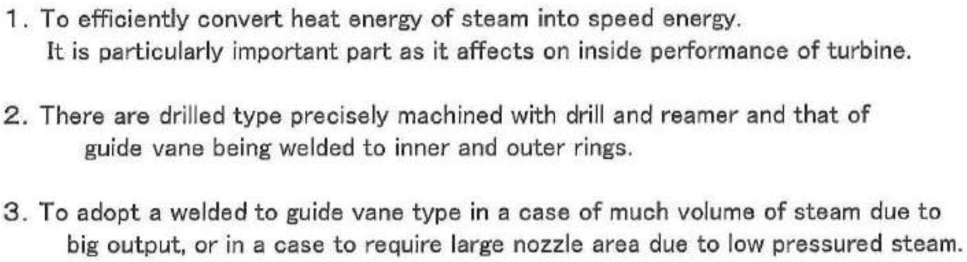
**7. Manual nozzle** : A valve to makeup steam when load fluctuates and steam energy lowers

**8. Critical speed :** Speed generated when individual vibration number and revolution speed become equal Fast passing this speed range at increasing speed, as vibration has characteristic to suddenly.

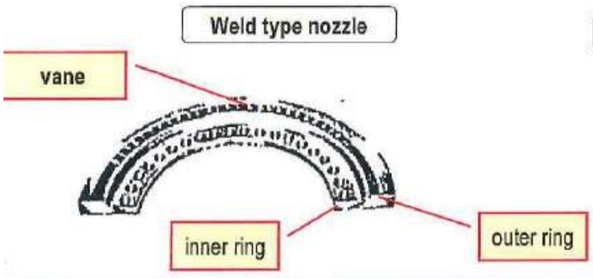


| Part under control (unit) | | Constituting Parts (name) |
|---|---|---|
| Turbine proper | Casing | casing |
| | Diaphragm, etc. | diaphragm, nozzle, stationary blade, diaphragm, inter stage labyrinth |
| | Rotor | shaft, disc, bucket(blade), shroud |
| | Shaft seal | labyrinth PK, carbon ring(PK) |
| | Bearing | radial bearing, thrust bearing |
| | Over-speed trip | over-speed tripper, spring, liner |
| Auxiliary | Governor structure | driving shaft, bearing, driving gear, mechanical hydraulic governor, electric governor |
| | Emergency cutout valve<br>Stem adjusting valve | stem, valve plug, busing, valve seat, link bearing, servo piston |
| | Coupling | coupling |
| | Lubrication equipment | pump, filter, oil cooler, hydraulic adjusting valve, temperature adjusting valve, oil tank |
| Support of body | | foundation, base plate, pedestal |

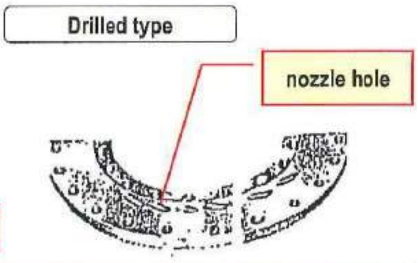
## NOZZLE



1. To efficiently convert heat energy of steam into speed energy.
   It is particularly important part as it affects on inside performance of turbine.
2. There are drilled type precisely machined with drill and reamer and that of guide vane being welded to inner and outer rings.
3. To adopt a welded to guide vane type in a case of much volume of steam due to big output, or in a case to require large nozzle area due to low pressured steam.

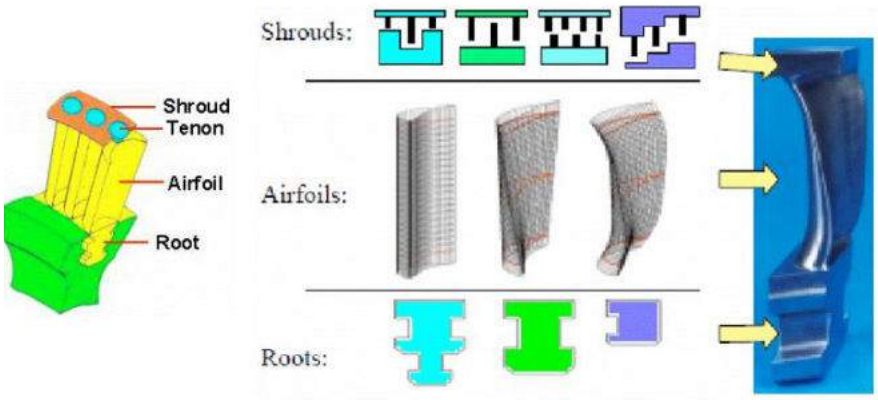


Weld type nozzle

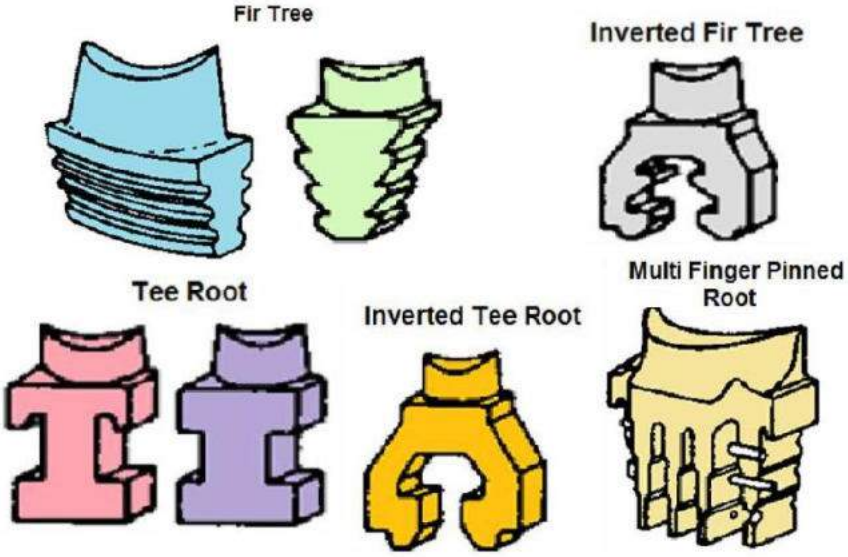


Drilled type

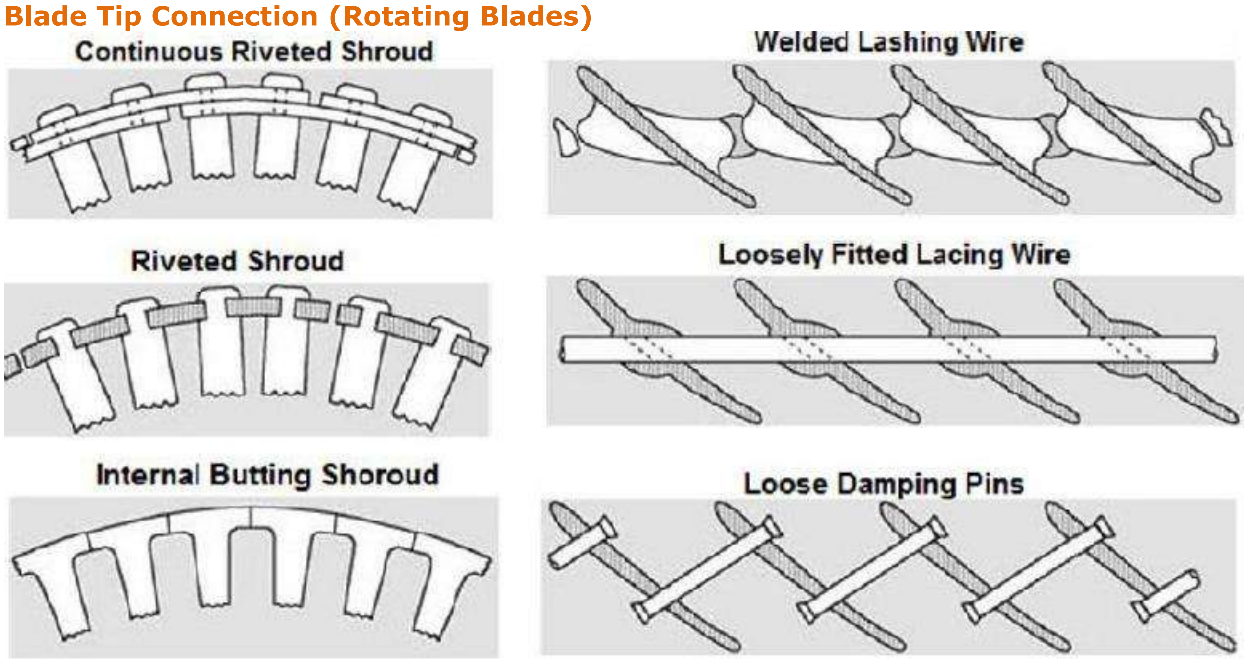
## BLADE


Shroud
Tenon
Airfoil
Root
Shrouds:
Airfoils:
Roots:

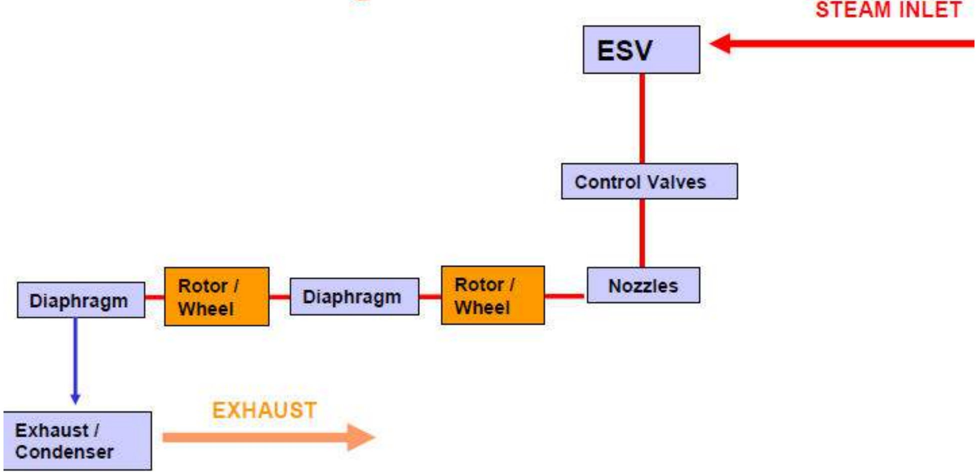
## Blade root design


Fir Tree
Inverted Fir Tree
Tee Root
Inverted Tee Root
Multi Finger Pinned Root

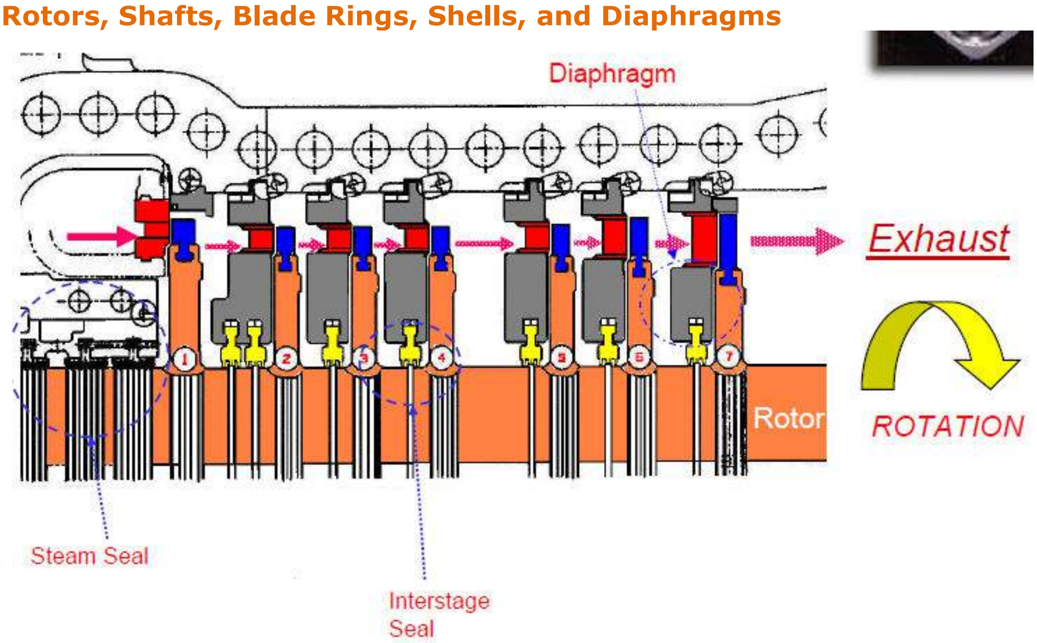
## Blade Tip Connection (Rotating Blades)


Continuous Riveted Shroud
Welded Lashing Wire
Riveted Shroud
Loosely Fitted Lacing Wire
Internal Butting Shoroud
Loose Damping Pins

## *Steam Path Through Turbine*


STEAM INLET
ESV
Control Valves
Nozzles
Rotor / Wheel
Diaphragm
Rotor / Wheel
Diaphragm
Exhaust / Condenser
EXHAUST

## Discs, Rotors, Shafts, Blade Rings, Shells, and Diaphragms



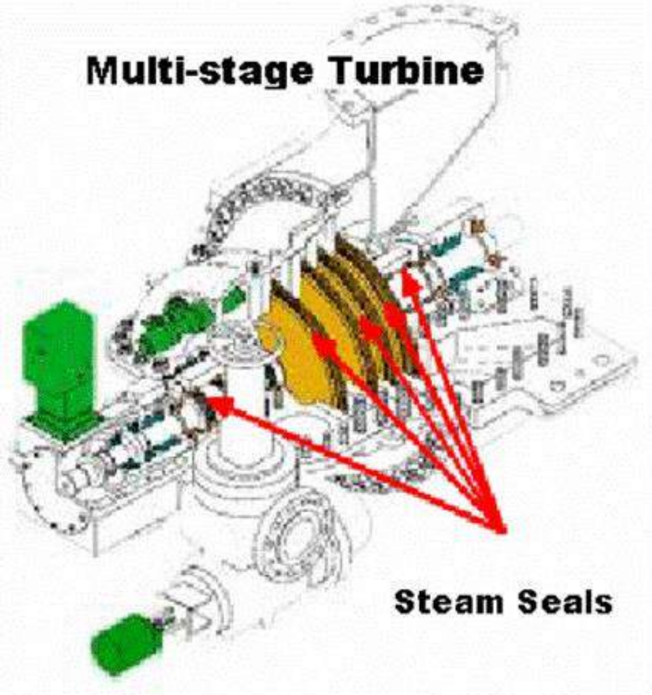
To transmit the torque produced in each stage of the turbine, the rotating blading is fastened to discs or wheels through a specially designed attachment shape at the blade base or root. The root shape may be fir-tree, T-slot, or semi-circular fir-tree shaped or may use multiple pins to hold the blades to the discs. The turbine discs may be shrunk fit onto a shaft with an anti-rotation key or the discs may have been forged with the shaft as an integral assembly. The output shaft from the shrunk fit or integral disc rotor is then connected to the driven equipment through a flange connection or flexible coupling. Similarly, stationary blading roots may be attached to slots in shells, casings, or blade rings or where the stationary blading is welded to support rings to create a stationary blading assembly referred to as a diaphragm. Depending on the pressure and temperature of the steam to the turbine, there may be dual sets of shells or casings; an inner shell which holds the stationary blading and an outer shell which acts as pressure boundary for the turbine as well as accommodating attachment of blade rings. The mass and thermal inertial of steam turbine rotors and shells can be quite large. As such, the temperature gradients the rotors and shells can encounter during starting and transients need to be controlled carefully otherwise there can be serious rubs between the rotating and stationary parts and/or there can be extensive distortion of rotors and/or shells when the gradients are too large or occur too fast. Steam turbine discs, rotors, shafts, shells, blade rings, and diaphragms are subjected to the same failure mechanisms and causes that apply to steam turbine blading. It is not uncommon to encounter permanent deformation (creep), fatigue cracks (thermal and vibratory), and stress corrosion cracking in discs, rotors, shells, and diaphragms. Unlike blading, the mechanisms may take longer for the resultant damage to become detectable as these parts tend to be more robust in size.

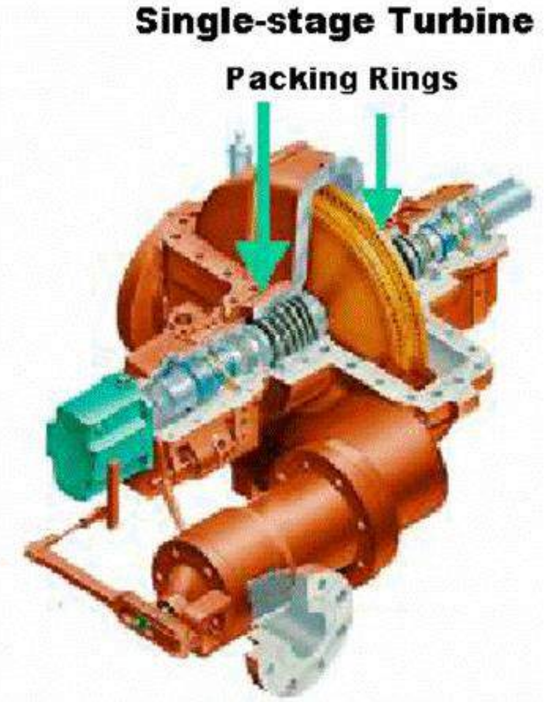
## Bearings and Lubrication Systems

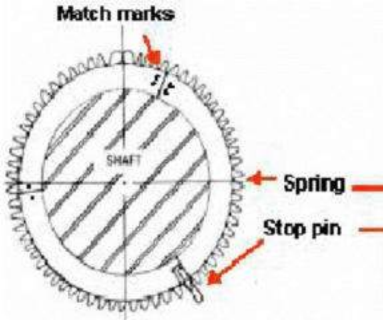
As with most rotating machinery, bearings are utilized to support the turbine rotor inside housings installed in the turbine shells. Depending on the size and number of stages of the steam turbine, different types of bearings may be utilized. It is common for smaller steam turbines to utilize rolling element bearings while larger turbines will utilize journal and multi-pad thrust bearings. Regardless of the type of turbine, there needs to be a complete lubrication system that reliably provides clean, cool lube oil to the turbine bearings. For many large steam turbines, shaft lift oil systems are utilized to lift the shaft in their journal bearings during starting and to keep the shaft lubricated during coast down of the turbine rotor after steam to the turbine is shut off. For some turbines, lube oil (usually mineral oil) is utilized to power servomotors and actuators for stop and control valves. In other cases, hydraulic fluids (usually phosphate-ester type fluids), which can operate at higher pressures and temperatures without ignition, are utilized to provide the required power for the valves. Properly designed and maintained lube oil or hydraulic fluid systems are extremely important. Most oil systems, as a minimum, need to include an oil reservoir with level indication, filters and separators (particulate and water removal), pumps (primary and emergency backup that are independent of the primary pump system), pressure switches or sensors to detect loss of oil pressure, and heat exchangers to cool the oil. Most concern is protecting the turbine from loss of lube oil incidents which may involve the loss of oil pressure detectors (pressure switches and controls) or backup lube oil pump(s) and/or their starting logic not working properly. Since oil is utilized to lubricate and cool turbine bearings (and gearbox gears and bearings, if present) and actuate major turbine valves, it is important that the oil be free of dirt, moisture, foaming, and any contaminants which would cause damage to bearings, servomotors, and valve actuators. Some contaminants are removed by filters, but removal of water requires water separators, oil purifiers, or centrifuge type filter systems. Oil coolers can also be a source of water as leaks tend to flow from higher pressure (water) to the lower pressure oil system in the cooler. Oil does oxidize in the presence of water and will have a limited life. As such, conducting frequent sampling of lube oil and hydraulic fluids for particulates, water, contaminants, and remaining life is important. The reliability of the lube oil system is important as loss of lube incidents have been both frequent and severe events for all sizes of turbines. As such, periodic checks of loss of lube protection devices and logic need to be conducted.

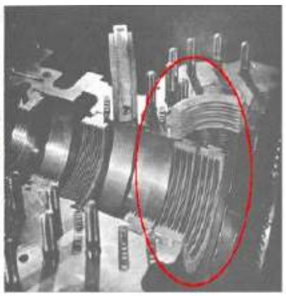
## Steam and Oil Seals

In order to keep the steam from going around the stationary and rotating blading, steam turbines utilize seals to keep the steam confined to the flow path. Depending on the size and type of steam turbine, various types of steam seal designs (carbon rings, labyrinth, retractable labyrinth, brush) may be utilized. These systems are usually pressurized with steam to minimize the pressure differential across these seals so that leakage from the higher pressure parts of the turbine is less likely to occur. Similar type seals are utilized to keep bearing oil confined to the bearing housing. As such, seal systems may have filters, pressure regulators, coolers, and the like to maintain a seal pressure as required. Severe rubbing of new seals after overhaul or during transients operation, particularly starting, continues to cause steam turbine forced outages.

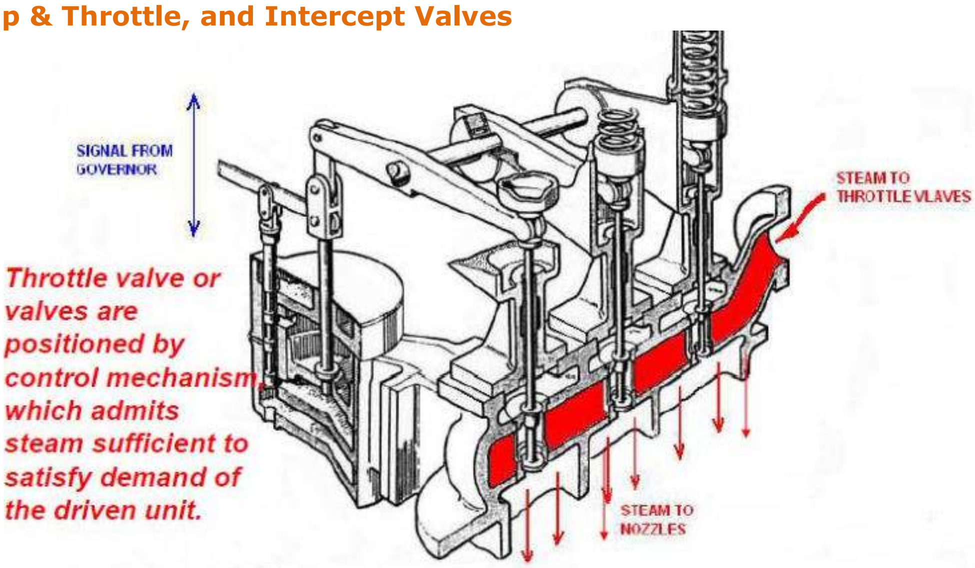








## Stop, Trip & Throttle, and Intercept Valves



*Throttle valve or valves are positioned by control mechanism which admits steam sufficient to satisfy demand of the driven unit.*

Important to any turbine is the ability to start and stop the machine under normal (controlled) and emergency conditions. For steam turbines, being able to shut off the steam supply quickly and reliably is required. This is normally accomplished by either main steam (MS) stop valves or trip and throttle (T&T) valves which are usually installed in the inlet piping to the steam turbine or on the turbine shell. The valves are designed to be leak tight otherwise any steam leakage may keep the turbine turning at low speed after shutdown or causing an over speed because the valve did not close completely after a shutdown or trip.

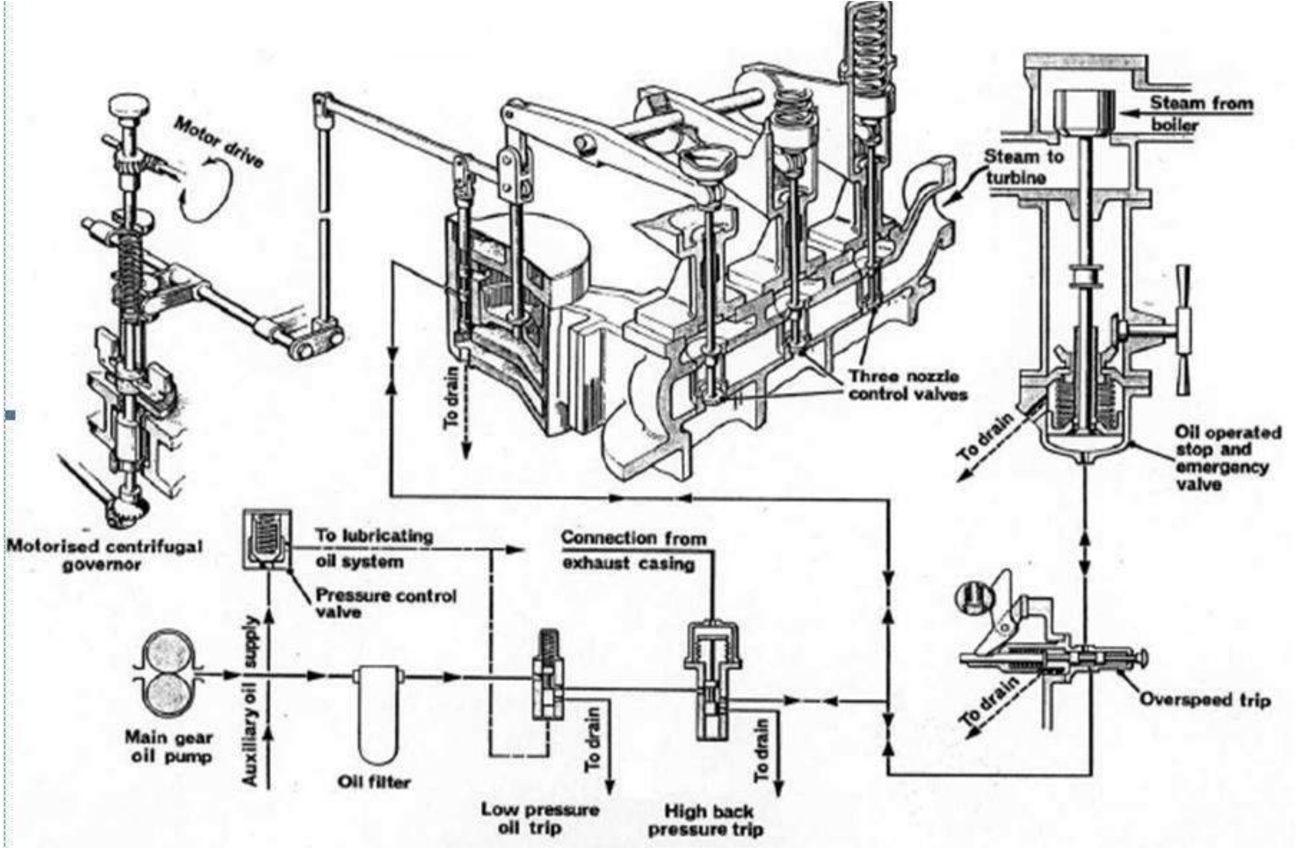
For most applications, actuators for these valves are powered by high-pressure hydraulic system fluid or lube system oil. Hydraulic or lube system pressure powers servomotors to open the valves while loss of oil pressure results in spring-load closing of the valve in a fail-safe condition (closed). For some old and small steam turbines, the stop valve may be a manual valve with a large hand wheel. The same valve may also be used for starting the unit. In addition, there may be hand operated valves mounted in the nozzle inlet for manually increasing steam to the turbine.

For reheat type steam turbines, which direct steam back to a boiler super heater section for reheating after going through the high pressure section of the turbine, there are additional valves installed between the high pressure section and subsequent section of the turbine.

Reheat stop valves are used for leak tight protection but a faster active valve called an intercept valve is installed in series or combination with the reheat stop valves in order to prevent over speeds. The valves also open with oil pressure and are spring-loaded closed when oil pressure is reduced to zero under trip and over speed conditions.

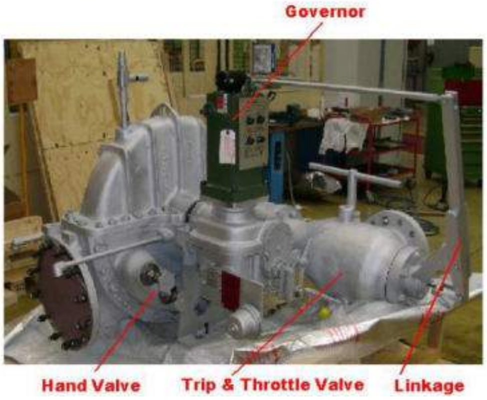
These valves provide fundamental over speed protection to the steam turbine and need to be tested, inspected, and overhauled routinely as contaminants in the steam, wear of mating valve parts, or damaged valve seats can cause sticking or leaking of these valves in service.

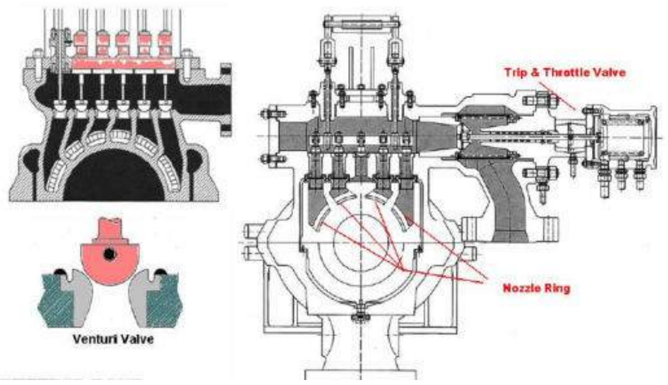
## Governor/Control Valves


Motor drive
Steam from boiler
Steam to turbine
To drain
Three nozzle control valves
To drain
Oil operated stop and emergency valve
Motorised centrifugal governor
To lubricating oil system
Pressure control valve
Connection from exhaust casing
Auxiliary oil supply
Main gear oil pump
Oil filter
To drain
To drain
To drain
Overspeed trip
Low pressure oil trip
High back pressure trip

Steam flow is introduced to the nozzle rings via a trip & control valve. Hand valve (s) are used to adjust extra power requirements

Steam enters the nozzle boxes by the trip valve. Load is adjusted by a series of individual nozzle rings ported valves, bar or cam operated, according to load demand


Governor
Hand Valve
Trip & Throttle Valve
Linkage


Trip & Throttle Valve
Venturi Valve
Nozzle Ring

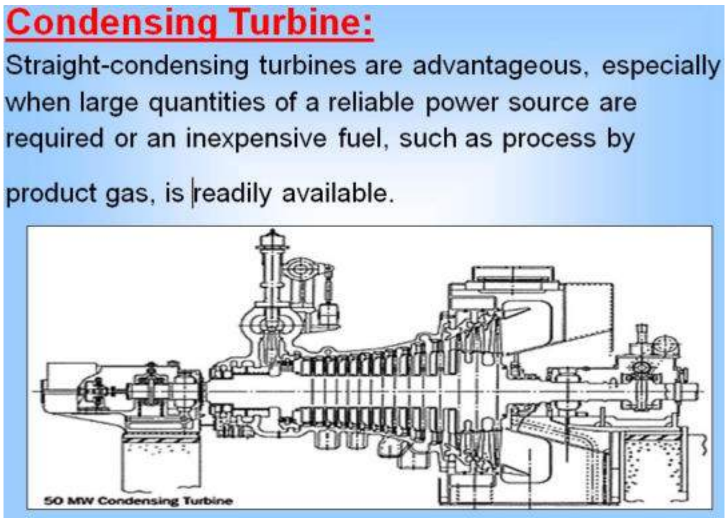
Control valves are provided on the turbine shell to regulate the flow of steam to the turbine for starting, increasing/decreasing power, and maintaining speed control with the turbine governor system. Several different valve arrangements are utilized. These include a single inlet valve with separate actuator, cam lift inlet valve assemblies, and bar lift inlet valve assemblies. The valve assemblies are normally mounted onto a steam chest that may be integral to the shell or bolted to it. The cam lift valve arrangement utilizes cams, bearings, and bushings which are mounted on camshaft to regulate the position of each valve. A hydraulic servomotor drives a rack and pinion connection to the camshaft to indicate the position desired by the governor. In the bar lift valve arrangement, a hydraulic cylinder lifts all of the valves attached to the bar together, but the collars on each valve stem are set at different heights and opening sequencing for admitting steam during starting and load changes. These valves need to be cycled routinely to minimize the potential for the valves to stick. When the valves stick open or closed, the turbine is put into jeopardy as a result of losing the ability to control the turbine (i.e., increase or reduce load).

## Admission, Extraction, and Non-Return Valves (NRV)

In addition to the traditional stop and control valves, many steam turbines have additional ports installed on the turbine to admit or extract steam. Steam turbines designed to admit steam not only at the turbine inlet but also at a lower pressure locations in downstream sections of the turbine are referred to as admission turbines. These turbines are utilized primarily in applications (steel mills, paper mills, combined cycle plants with triple pressure HRSG's) where additional steam flow at lower pressures is available to make additional power.

In addition to providing additional sources of steam to the turbine, the turbine can also be a source of steam for facility services at various pressures and flows. Turbines with this kind of capability are referred to as extraction turbines and may be described by the number of extractions (single, dual, etc.). Steam is taken from the turbine at various stages to match with the facility's pressure and flow requirements. The extractions can be categorized as controlled or uncontrolled, as well as automatic or manual. Some extractions are utilized for feed water heating. The extraction control valves typically have two functions; to regulate the steam flow externally and to maintain the extraction steam pressure constant. The valves are hydraulically opened and spring-loaded shut. They are, however, not designed to be leak tight and will typically pass 5% steam flow in the closed position. Non-return valves (NRV) or check valves are normally installed downstream of the controlled and uncontrolled (i.e., no regulating or control valve) extraction connections to the turbine. The function of the valves is to permit flow of extraction steam in the outgoing direction and prohibit backward flow into the turbine when turbine extraction pressure is lower than the lines it feeds.

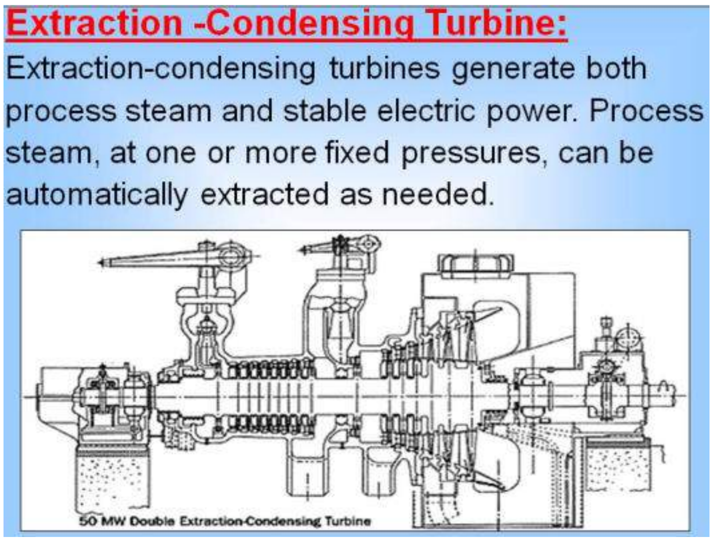
The valves are designed to be spring-loaded shut when there is no extraction pressure but they also have an air or hydraulically assisted actuator to close the valve when the systems are pressurized. Malfunctioning of extraction NRV's is the primary cause of over speed damage during turbine shutdown. As such, these valves need to be tested, inspected, and overhauled on a frequent basis.



### Condensing Turbine:

Straight-condensing turbines are advantageous, especially when large quantities of a reliable power source are required or an inexpensive fuel, such as process by product gas, is readily available.

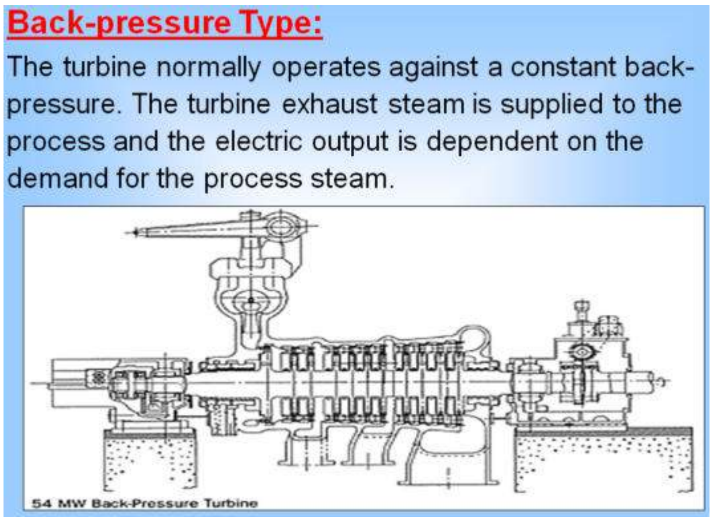
50 MW Condensing Turbine



### Extraction -Condensing Turbine:

Extraction-condensing turbines generate both process steam and stable electric power. Process steam, at one or more fixed pressures, can be automatically extracted as needed.

50 MW Double Extraction-Condensing Turbine

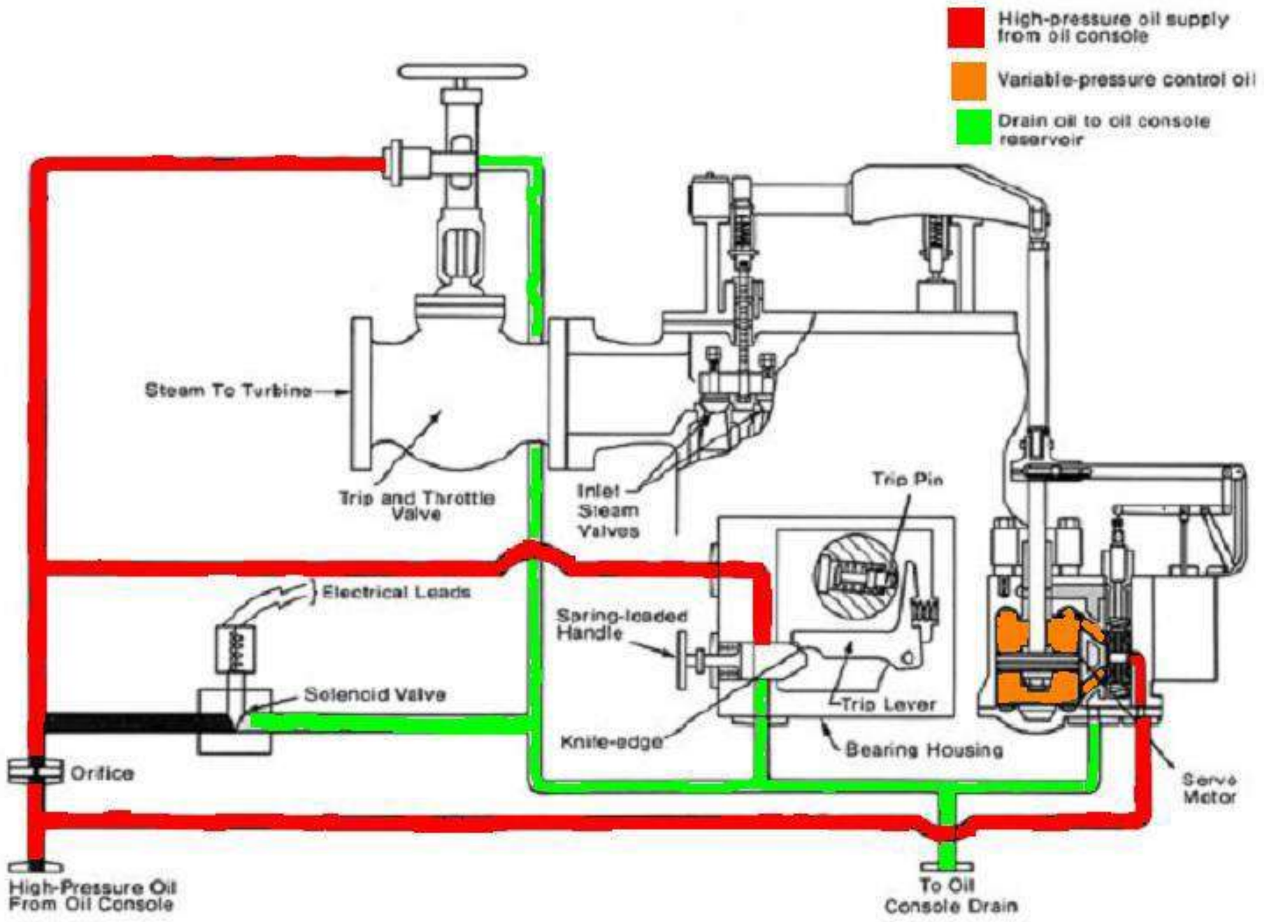


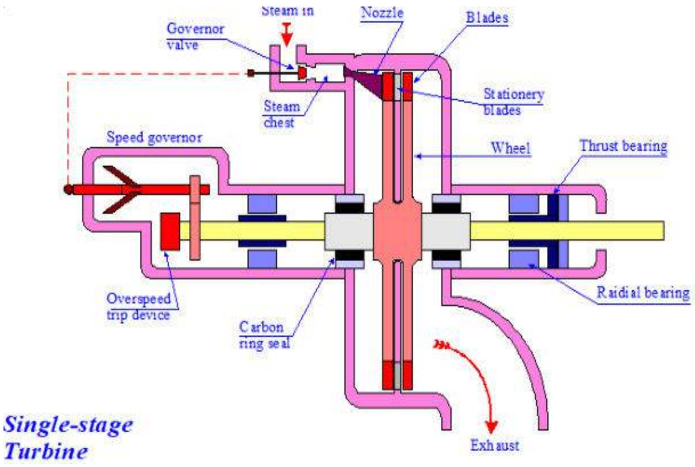
### Back-pressure Type:

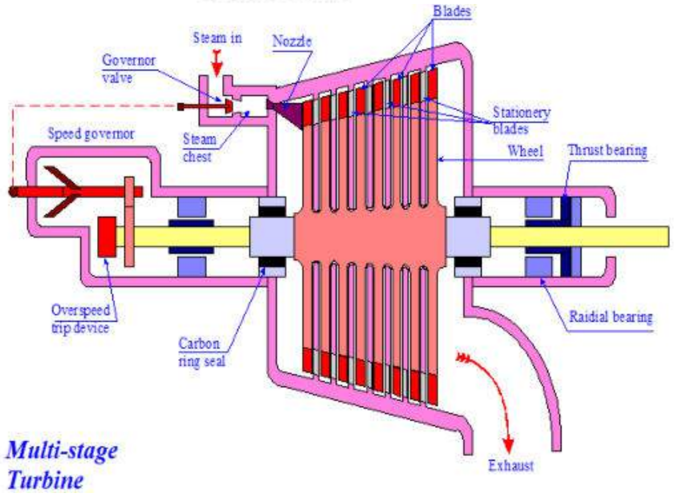
The turbine normally operates against a constant back-pressure. The turbine exhaust steam is supplied to the process and the electric output is dependent on the demand for the process steam.

54 MW Back-Pressure Turbine

## Turbine Over speed Protection and Trip Logic


High-pressure oil supply from oil console
Variable-pressure control oil
Drain oil to oil console reservoir
Steam To Turbine
Trip and Throttle Valve
Inlet Steam Valves
Trip Pin
Electrical Leads
Spring-loaded Handle
Solenoid Valve
Knife-edge
Trip Lever
Bearing Housing
Orifice
Servo Motor
High-Pressure Oil From Oil Console
To Oil Console Drain


Steam in
Nozzle
Blades
Governor valve
Steam chest
Stationery blades
Speed governor
Wheel
Thrust bearing
Overspeed trip device
Carbon ring seal
Raidial bearing
Exhaust
Single-stage Turbine


Blades
Steam in
Nozzle
Governor valve
Speed governor
Steam chest
Stationery blades
Wheel
Thrust bearing
Overspeed trip device
Carbon ring seal
Raidial bearing
Exhaust
Multi-stage Turbine

The most destructive event for a steam turbine is an overspeed event as the steam turbine and its driven equipment are usually catastrophically damaged. These events, while infrequent, continue to occur on both small and larger steam turbines regardless of the vintage, technology level, application, or type of control system (digital, analog, hydro-mechanical, mechanical) associated with the steam turbine.

A steam turbine may utilize a mechanical overspeed protection system, electronic overspeed protection system, or combination of systems to maximize protection. The mechanical overspeed device consists of a spring-loaded piston mounted in the turbine shaft at the front of the turbine. When turbine speed reaches an overspeed condition (i.e., 10% above running speed), the piston pops out and hits an oil dump valve lever which causes depressurization of the oil supply to the stop, trip and throttle, and intercept valves. This results in all stop and intercept valves immediately closing. Many mechanical systems also utilize a flywheel ball governor driven by the turbine shaft. Any change in governor position is converted to a change in oil pressure to the turbine control valve servomotor or actuator. Under overspeed conditions, the flywheel governor will hit the oil dump valve lever to close the steam stop valve.

With electronic systems, numerous magnetic speed pickups are installed on the turbine shaft. The turbine control system and software logic will electronically open the oil dump valve to depressurize the oil system and close all stop and intercept valves. There are various versions of electronic overspeed systems in service. Some include both primary and backup (emergency) systems that operate independently. Some include test switches to test the primary system for proper operation without actually tripping the turbine. For most turbines the overspeed protection system will also cause or command the turbine control valves to close as well. Because the control valves are not leak tight by design and their closure rate is much slower than stop and intercept valves, they are not considered to provide any overspeed protection.

In addition to the type of overspeed protection provided, the trip logic utilized by the control system to open the circuit breaker associated with the steam turbine's generator does have some effect on the performance of the protection. Typically, two trip schemes are utilized; sequential tripping and simultaneous tripping. Sequential tripping is when the steam turbine is always tripped first and the generator circuit breaker opens when the turbine speed and decaying power has decreased sufficiently to cause the generator reverse power relay to open the breaker. The method is typically utilized with large steam turbines operating at high steam inlet pressures and temperatures where it is desired to dissipate the energy in the turbine before opening the breaker to minimize the overspeed level on shutdown. Simultaneous tripping is utilized when both the turbine stop or trip and throttle valve and the generator circuit breaker are opened at the same time, regardless of whether the turbine or generator protection system initiated the trip. This type system is utilized successfully on small to medium size steam turbines where the steam pressures and temperatures are low and there is little steam volume in the turbine to cause an increase in speed on shutdown. Regardless of the type of overspeed and trip protection systems provided, the system needs to be regularly tested by simulation and by actual testing of the complete system.

## Type of Steam

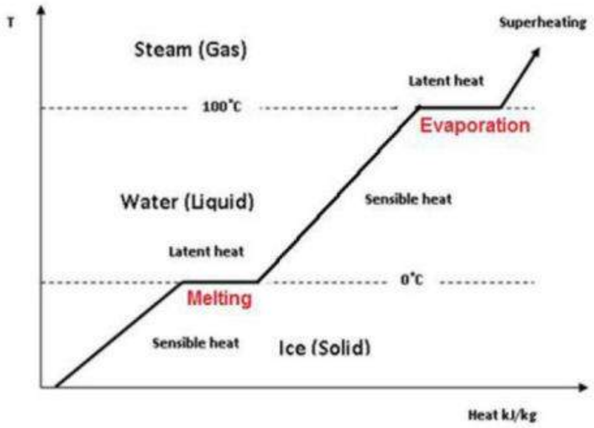
The steam utilized in steam turbines can be in **three different states: saturated, superheated, and supercritical.**

**Saturated steam** is produced when heat water to the boiling point or vaporization temperature for a given pressure. Under those conditions, you have very hot water and a steam vapor that is given off at the water interface, similar to what happens in a tea pot. However, for steam turbines, the boiling occurs in the boiler steam drum where the steam is separated from the liquid water that it came from. Depending on the pressure and temperature of the water being heated, the steam may still contain a portion of entrained water unless it is heated further to vaporize the remaining water content. Steam turbines do not like water in their steam so the steam is heated until all of the remaining water has vaporized. Saturated steam may be heated to a higher temperature at the same pressure in other boiler sections referred to as superheaters or reheaters. Saturated steam heated to these higher temperatures is then referred to as superheated steam. Steam turbines which utilize **superheated and saturated steam** are often referred to as subcritical steam turbines.

If the pressure of the superheated steam is increased further until the thermodynamic critical point of water is reached (221 bar/3,205 psi), then the steam is referred to as **supercritical steam**. This steam has the characteristic of passing from a liquid (water) to a vapor (steam) state without going through an intermediate liquid and vapor phase. This means a boiler drum is not needed as the heated water directly converts to vapor with no moisture to separate or reheat. Turbines utilizing this type of steam are referred to as supercritical turbines. If the pressure of the steam is increased to 370 bar (5,365 psi), the plants are referred to as ultra-supercritical plants.

As would be expected, as the temperature and pressure of steam increase, the complexity, materials, and the costs of the steam turbines will increase accordingly. Typically, smaller steam turbines utilize saturated steam. Most industrial and power plant applications use superheated steam, and most advanced power plants are moving towards supercritical steam. The supercritical units have higher efficiencies, produce less emissions, need less fuel, but tend to require more advanced and thicker materials to deal with both the higher pressures (370 bar/5,365 psi) and temperatures (720°C/1,328°F). Of course, the costs are higher as well.

- **Steam:** vaporized water, transparent gas that occupies, @ 100C & 1.014 bar (standard conditions), 1600 times the volume of equal mass of water.
- **Wet steam:** steam containing a fraction of water molecules in liquid state. It is measured by dryness fraction
- **Saturated steam:** steam at equilibrium with liquid water. Defines the boundary between wet steam and superheated steam on the phase diagram. Saturation temperature is pressure dependent, it
- increases with pressure increase
- **Dry steam:** steam with all it's water molecule in gaseous state
- **Superheated steam:** steam at a temperature higher than its boiling point at a given pressure. Superheating takes place only after all the liquid water has evaporated.
  Steam 'specific volume decreases with pressure



• Small Units (0.5 - 2 MW): 150-400 psi/500-750°F (10-30 bar/260-400°C)
• Medium Units (1.5 - 10 MW): 400-600 psi/750-825°F (10-42 bar/400-440°C)
• Large Units (4 - 100 MW): 600-900 psi/750-900°F (42-62 bar/400-482°C)
• Large Units (10-1,000 MW): 900-2,400 psi/825-1,050°F (62-166 bar/440-566°C)
• Supercritical Units (>200 MW): 3,625-5,365 psi/1,010-1,328°F (250-370 bar/ 540-720°C)

## Grouping and Number of Turbine Stages

Turbines are often described by the number of stages. For example, single stage turbines are usually small units that drive pumps, fans, and other general purpose equipment in a facility. For medium size steam turbines that drive air conditioning chillers or generators, 4 to 10 stages may be utilized. In large size units, there may be 12 to 40 stages driving generators or other equipment. These stages may be grouped into different sections of the turbine. The section with the highest pressure levels is called the high pressure (HP) section. The intermediate pressure (IP) section has the mid-level pressure levels. The low pressure (LP) section has the lowest pressure levels and discharges to the condenser or backpressure system. The turbine sections can be packaged into separate sections in a single turbine casing, into separate casings for each section, or in combination (HP/IP turbines in one casing and LP turbine in another). In addition, in many LP turbines and some HP and IP turbines, there are two turbines connected together in the same casing but in opposing directions to balance the thrust loads. Flow to these turbines is through the center of the casing and exits from each end of the turbine. These are referred to as turbines with double flows (i.e., opposing flow paths on same shaft). The MW rating of the steam turbine, however, may not be indicative of the number of sections or casings which make up the turbine. This is exemplified in Figure where turbine could consist of 2, 3 or 4 casings. Of course the fewer number of casings and stages for the same steam conditions results in high loadings and larger size blading for these model turbines, particularly in the last stage. The selection of which configuration is utilized is dependent on economics (cost and efficiency) and customer desires. Consistent with the variation in the number of turbine casings, the last stage blades in the LP section, which is the largest blade in the turbine, may range in size and materials over a broad range. Blade Figure shows a typical suite of blade sizes that a manufacturer may utilize in their steam turbines. Several manufacturers are now utilizing titanium material for the last stage blades because of the lighter weight and improved corrosion resistance as compared to steel blades. Unfortunately, whether made from titanium or steel, these large blades are usually the most expensive in the turbine and the most likely to fail with time.

## Equipment Monitoring

To effectively manage the health and performance of steam turbines, there are a number of turbine parameters which should be measured, monitored and/or displayed on a continuous basis.

**The following parameters should be monitored:**

- Speed (RPM) and load (kW/MW, or shaft horsepower (SHP))
- Steam turbine inlet pressure and temperature
- Steam turbine 1st stage pressure and temperature (these are the conditions downstream of the First/large impulse stage before remaining HP section blading, as applicable)
- HP turbine outlet (or cold reheat), IP turbine inlet (or hot reheat), and IP turbine outlet/LP turbine inlet (or crossover) pressures and temperatures for reheat and multiple shell turbines only
- Steam turbine rotor/shell differential expansions (as applicable for large turbines)
- Steam turbine shell and steam chest temperatures/differentials (lower and upper half thermocouples installed in HP and IP turbine sections for large turbines)
- Admission and extraction pressures and temperatures (as applicable)
- Extraction line thermocouples to detect water induction (as applicable)
- Water and steam purity at the main steam inlet and condensate pump discharge
- Sealing steam and exhauster pressures (as applicable)
- Steam turbine exhaust pressure and temperature
- Lube oil and hydraulic fluid supply pressures and temperatures
- Cooling water supply pressures and temperatures for the lube oil and hydraulic fluid systems
- Journal bearing and thrust bearing metal temperatures (or drain temperatures, if applicable) for the turbine and gearbox (as applicable)
- Bearing vibration – seismic, shaft rider or shaft x-and-y proximity probes measurements for all turbine and gearbox (pinion) bearing locations (as applicable), Monitoring of these and other parameters is typically done in conjunction with today’s modern turbine digital controls and plant control room systems.

These systems will also handle the starting sequence, synchronizing, loading, speed governing, alarms, and trip logic for the turbine, gearbox (if present), generator, and any supporting systems. These systems also provide the electronic portion of the protection (i.e., turbine over speed) for critical turbine and generator parameters.

## Water and Steam Purity Monitoring

Contaminated steam is one of the prime causes of forced and extended maintenance outages and increases in maintenance costs. Contaminants can be introduced into steam from a variety of sources but can generally be categorized into two categories:

1) Inert or deposit forming and
2) Reactive or corrosion causing.

**The sources of contamination include the following:**

- Water treatment chemicals for the boiler or condensate system
- Condenser leaks
- Demineralizer leaks
- Chemical cleaning of the boilers
- Process chemicals
- Makeup water which may have rust, silica and other chemicals
- Corrosion products from condenser tubes and condensate piping.

**The principal cause of small to moderately large steam turbine contamination is mechanical carryover from the boiler system. These can result from:**

- Over steaming
- High water levels
- High drum solids
- Separator problems
- Rapid load changes
- Chemical contamination

To systematically minimize these effects, design and implementation of water and steam chemistry controls that protect the boiler and turbine need to be established, superheater attemperation operation needs to be prudent, and steam purity monitoring needs to be implemented. The monitoring for the steam turbine, as a minimum, should include sodium and cation conductivity monitoring at the steam inlet to the turbine. In addition, it is advisable to monitor sodium and cation conductivity in the condensate and feedwater system downstream of the condensate pumps or demineralizer and at the deaerating (DA) tank outlet or economizer inlet to provide advance warning of water chemistry problems. Together, cation conductivity and sodium monitoring allow for the detection of the primary chemical causes (chlorides, sulfates, hydroxides) that are responsible for stress corrosion cracking of turbine steels. While other parameters (silica, hardness, etc.) in the water/steam may be monitored, their effect on turbine reliability is small compared to the primary chemical causes.

### Water Induction Monitoring

Significant turbine damage can occur to a steam turbine when cool water or steam flows back into the turbine. When this happens during operation, steam turbine nozzle and/or bucket vibration increases and increases the potential for these components to break in the vicinity of where the cool water or steam is being introduced. Similarly, if the cool water or steam backflow occurs during starting, it can thermally distort the steam turbine rotor during the start and may cause major seal rubs and severely damaged blades. If the water or steam induction occurs during a shutdown after the circuit breaker has been opened, the turbine can and does overspeed to destruction.

**The following is suggested as the minimum basic requirements to detect and reduce the probability of water or cool steam induction:**

- Test extraction non-return valves (NRV) daily to ensure proper operation
- Install and monitor thermocouples on the controlled and uncontrolled extraction lines to detect drops in temperature that may be indicative of a potential water induction incident
- Ensure sealing steam drains and casing drains are free, that valves installed downstream of drains are in the proper position, that drains are not manifolded together to restrict flow, and that the drain lines actually drain downward
- Ensure that feedwater heater (if present) levels are kept at required levels and that level detector alarms are added to alert the operator of a problem
- Ensure steam header low point drains, main steam stop and T&T valve drains, control/extraction valve drains have valves in the proper position for draining and that the drain lines do drain downward, not upward
- Ensure attemperation spray control valves close on boiler fuel and turbine trips and that there is a block or shutoff valve in series with the spray control valve to ensure there is no leakage into the turbine
- Monitor the difference in thermocouple readings (if present) on the upper and lower halves of the turbine shell. A large difference between halves and/or a cooler lower half could be indicative of water induction

### What basic governor troubles are apt to occur?

Hunting-alternate speeding and slowing of the engine, which means that the governor is too sensitive to load changes. Sticking-failure to control speed, allowing the engine to run away or slow down-which means that the governor is not sensitive to load changes or parts are binding or worn.

### What is a governor safety stop?

On throttling-type governors, the safety stop is a weighted arm that needs the support of a governor belt. If the belt breaks, the idler arm drops and shuts the steam supply valve to the engine, the fly balls fall to the lowest position and knock off the safety cams; the cams disengage the catch blocks on the steam intake valves so that no steam is admitted to the engine.

### Why should a steam or moisture separator be installed in the steam line next to a steam turbine?

All multistage turbines, low-pressure turbines, and turbines operating at high pressure with saturated steam should have a moisture separator in order to prevent rapid blade wear from water erosion.

### Why is it necessary to open casing drains and drains on the steam line going to the turbine when a turbine is to be started?

To avoid slugging nozzles and blades inside the turbine with condensate on start-up- this can break these components from impact. The blades were designed to handle steam not water.

**What three methods are used to restore casing surfaces that are excessively eroded?**

- Metal-spraying.
- Welding.
- Insertions of filler strips or patch plates. The manufacturer should be consulted on the metallurgy involved so that the best method can be selected.

**What is a stage in a steam turbine?**

In an impulse turbine, the stage is a set of moving blades behind the nozzle.
In a reaction turbine, each row of blades is called a "stage." A single Curtis stage may consist of two or more rows of moving blades.

**What is a diaphragm?**

Partitions between pressure stages in a turbine's casing are called diaphragms. They hold the vane-shaped nozzles and seals between the stages. Usually labyrinth-type seals are used. One-half of the diaphragm is fitted into the top of the casing, the other half into the bottom.

**What are four types of turbine seals?**

- Carbon rings fitted in segments around the shaft and held together by garter or retainer springs.
- Labyrinth mated with shaft serration’s or shaft seal strips.
- Water seals where a shaft runner acts as a pump to create a ring of water around the shaft. Use only treated water to avoid shaft pitting.
- Stuffing box using woven or soft packing rings that are compressed with a gland to prevent leakage along the shaft.

**What are two types of clearance in a turbine?**

- **Radial** - clearance at the tips of the rotor and casing.
- **Axial** - the fore-and-aft clearance, at the sides of the rotor and the casing.

**What are four types of thrust Bearings?**

- Babbitt-faced collar bearings.
- Tilting pivotal pads.
- Tapered land bearings.
- Rolling-contact (roller or ball) bearings.

**What is the function of a thrust bearing?**

Thrust bearings keep the rotor in its correct axial position.

**What is a balance piston?**

Reaction turbines have axial thrust because pressure on the entering side is greater than pressure on the leaving side of each stage. To counteract this force steam is admitted to a dummy (balance) piston chamber at the low-pressure end of the rotor. Some designers also use a balance piston on impulse turbines that have a high thrust. Instead of piston, seal strips are also used to duplicate a piston's counter force.

**What is a combination thrust and radial bearing?**

This unit has the ends of the babbitt bearing extended radially over the end of the shell. Collars on the rotor face these thrust pads and the journal is supported in the bearing between the thrust collars.

**What is a tapered-land thrust bearing?**

The babbitt face of a tapered-land thrust bearing has a series of fixed pads divided by radial slots. The leading edge of each sector is tapered, allowing an oil wedge to build up and carry the thrust between the collar and pad.

**What is important to remember about radial bearings?**

A turbine rotor is supported by two radial bearings, one on each end of the steam cylinder. These bearings must be accurately aligned to maintain the close clearance between the shaft and the shaft seals, and between the rotor and the casing. If excessive bearing wear lowers the rotor, great harm can be done to the turbine.

**What is gland-sealing steam?**

It is the low-pressure steam that is led to a sealing gland. The steam seals the gland, which may be either a carbon ring or labyrinth type against air at the vacuum end of the shaft.

**What is the function of a gland drain?**

The function of a gland drain is to draw of water from sealing-gland cavities created by the condensation of sealing steam.

**How many governors are needed for safe turbine operation? Why?**

Two independent governors are needed for safe turbine operation. One is an over speed or emergency trip that shuts off the steam at 10 percent above running speed (maximum speed). The second, or main governor, usually controls speed at a constant rate; however, many applications have variable speed control.

**How is a fly ball governor used with a hydraulic control?**

As the turbine speeds up, the weights are moved outward by centrifugal force, causing linkage to open a pilot valve that admits and releases oil on either side of a piston or on one side of a spring-loaded piston. The movement of the piston controls the steam valves.

**What is a multi-port governor valve? Why is it used?**

In large turbines, a valve controls steam flow to groups of nozzles. The number of open valves controls the number of nozzles in use according to the load. A bar-lift or cam arrangement operated by the governor opens and closes these valves in sequence. Such a device is a multi-port valve. Using nozzles at full steam pressure is more efficient than throttling the steam.

**What is meant by critical speed?**

It is the speed at which the machine vibrates most violently. It is due to many causes, such as imbalance or harmonic vibrations set up by the entire machine. To minimize damage, the turbine should be hurried through the known critical speed as rapidly as possible.

**How is oil pressure maintained when starting or stopping a medium-sized turbine?**

An auxiliary pump is provided to maintain oil pressure. Some auxiliary pumps are turned by a hand crank; others are motor-driven. This pump is used when the integral pump is running too slowly to provide pressure, as when starting or securing a medium-sized turbine.

**Why is it poor practice to allow turbine oil to become too cool?**

If turbine oil is allowed to become too cold, condensation of atmospheric moisture takes place in the oil and starts rust on the polished surfaces of the journal bearings. Condensed moisture may interfere with lubrication.

**Steam blowing from a turbine gland is wasteful. Why else should it be avoided?**

It should be avoided because the steam usually blows into the bearing, destroying the lubrication oil in the main bearing. Steam blowing from a turbine gland also creates condensate, causing undue moisture in plant equipment.

**Besides lubrication, which are two functions of lubricating oil in some turbines?**

In large units, lube oil cools the bearings by carrying off heat to the oil coolers. Lube oil in some turbines also acts as a hydraulic fluid to operate the governor speed-control system.

**Why is there a relief valve on a turbine casing?**

The turbine casing is fitted with spring-loaded relief valves to prevent damage by excessive steam pressure at the low-pressure end if the exhaust valve is closed accidentally. Some casings on smaller turbines are fitted with a sentinel valve, which serves only to warn the operator of over-pressure of the exhaust end. A spring-loaded relief valve is needed to relieve high pressure.

**Why must steam turbines be warmed up gradually?**

Although it is probable that a turbine can, if its shaft is straight, be started from a cold condition without warming up, such operation does not contribute to continued successful operation of the unit. The temperature strains set up in the casings and rotors by such rapid heating have a harmful effect. The turbine, in larger units especially should be warmed slowly by recommended warm-up ramp rates because of close clearances.

**What are the main causes of turbine vibration?**

- Unbalanced parts.
- Poor alignment of parts.
- Loose parts.
- Rubbing parts.
- Lubrication troubles.
- Steam troubles.
- Foundation troubles.
- Cracked or excessively worn parts.

**What is the purpose of a turning gear?**

Heat must be prevented from warping the rotors of large turbines or high-temperature turbines of 400°C or more. When the turbine is being shut down, a motor-driven turning gear is engaged to the turbine to rotate the spindle and allow uniform cooling.

**What does the term "ramp" rate mean “WARM UP CONDITION “?**

Ramp rate is used in bringing a turbine up to operating temperature and is the degrees Celsius rise per hour that metal surfaces are exposed to when bringing a machine to rated conditions. Manufacturers specify ramp rates or their machines in order to avoid thermal stresses. Thermocouples are used in measuring metal temperatures.

**What is the difference between partial and full arc admission?**

In multi-valve turbine inlets, partial arc admission allows the steam to enter per valve opening in a sequential manner, so as load is increased, more valves open to admit steam. This can cause uneven heating on the high-pressure annulus as the valves are individually opened with load increase. In full-arc admission, all regulating valves open but only at a percentage of their full opening. With load increase, they all open more fully. This provides more uniform heating around the high-pressure part of the turbine. Most modern controls start with full-arc and switch to partial arc to reduce throttling losses through the valves.

- **By monitoring the exhaust steam temperature, how can the blade deposition be predicted?**
    1. Immediately after the 1st commissioning, the different values of exhaust temperature for different steam flow rates are precisely determined and plotted against steam flow. This will produce the first actual graph. This is for a clean turbine.
    2. Similar graphs are to be drawn at later periods for comparing with the initial graph.
    3. A rise in exhaust steam temperature under the same conditions refers to deposit formation.
    4. An increase of exhaust steam temperature by more than 10% in the range of 70 to l00% steam flow, indicates inadmissible blade depositions. Shutdown is to be taken and blades are to be washed off deposits.

- **How does pressure monitoring ensure detection of turbine deposits?**
  1. Pressure of steam expanding in the turbine is measured at characteristic points, i.e., at the wheel chamber, points of pass-out, inlet/outlet of HP, IP and LP stages of the turbine.
  2. The turbine manufacturer provides the pressure characteristics in the form of graphs.
  3. At 1st commissioning, the user supplements these theoretical curves with those derived from actual measurements. These are actual pressure characteristics for a clean turbine. Now these pressure characteristics are compared with those obtained during operation in the later period.
  4. Under identical conditions, an increase in pressure shows the formation of deposits.
  5. For a steam throughput in the range 70-100%, an increase in wheel chamber pressure of more than 10% indicates severe blade depositions.

- **How can problems of "excessive vibration or noise" due to piping strain be avoided on steam turbines?**
  1. The inlet as well as exhaust steam lines should be firmly supported and free from piping stress to avoid strains from being imposed on the turbine.
  2. Adequate allowance should be made for expansion of steam pipes due to heat.
- **How can the deposits be removed?**
  1. **Water soluble** deposits may be washed off with condensate or wet steam.
  2. **Water insoluble** deposits are removed mechanically after dismantling the turbine.
  3. Experience shows that water soluble deposits are embedded in layers of water-insoluble deposit and when the washing process is carried out, water soluble parts of the deposit dissolve away leaving a loose, friable skeleton of water-insoluble deposits which then break loose and wash away.
- **How can the detection of deposits in a turbine be made during operation?**
  1. Pressure monitoring.
  2. Internal efficiency monitoring.
  3. Monitoring exhaust steam temperature.
  4. Monitoring specific steam consumption.
- **How does deposit formation on turbine blades affect turbine efficiency?**
  About 500 g of deposits distributed more or less evenly all over the blading section can bring down turbine efficiency by 1%.

- **How does the internal efficiency monitoring lead to the detection of turbine deposits?**
  1. Process heat drop.
  2. Adiabatic heat drop.
  3. The process heat drop and adiabatic heat drop are obtained from a Mollier-Chart for the corresponding values of steam parameters - pressure and temperature - at initial and final conditions.

**STEAM TURBINE BLADE FAILURE MECHANISM:**

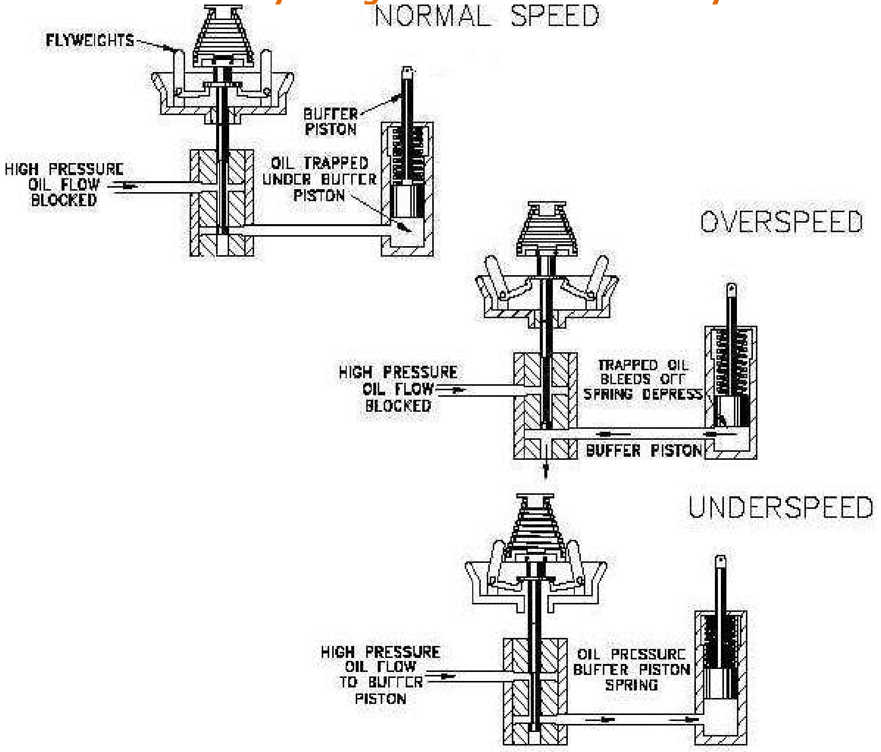
| Failure Mechanism | Resultant Damage | Cause(s) of Failure |
|---|---|---|
| Corrosion | Extensive pitting of airfoils, shrouds, covers, blade root surfaces | Chemical attack from corrosive elements in the steam provided to the turbine |
| Creep | Airfoils, shrouds, covers permanently deformed | Deformed parts subjected to steam temperatures in excess of design limits |
| Erosion | Thinning of airfoils, shrouds, covers, blade roots | 1) Solid particle erosion from very fine debris and scale in the steam provided in the turbine<br>2) Water droplet erosion from steam which is transitioning from vapor to liquid phase in the flowpath |
| Fatigue | Cracks in airfoils, shrouds, covers, blade roots | 1) Parts operated at a vibratory natural frequency<br>2) Loss of part dampening (cover, tie wire, etc.)<br>3) Exceeded part fatigue life design limit<br>4) Excited by water induction incident – water flashes to steam in the flowpath |
| Foreign/Domestic Object Damage (FOD/DOD) | Impact damage (dents, dings, etc.) to any part of the blading | Damage from large debris in steam supplied to the turbine (foreign) or damage from debris generated from an internal turbine failure (domestic) which causes downstream impact damage to components |
| Stress Corrosion Cracking (SCC) | Cracks in highly stressed areas of the blading | Specialized type of cracking caused by the combined presence of corrosive elements and high stresses in highly loaded locations |
| Thermal Fatigue | Cracks in airfoils, shrouds, covers, and blade roots | Parts subjected to rapidly changing temperature gradients where thick sections are subjected to high alternating tensile and compressive stresses during heat-ups and cooldowns or when a water induction incident occurs where the inducted cool water quenches hot parts |

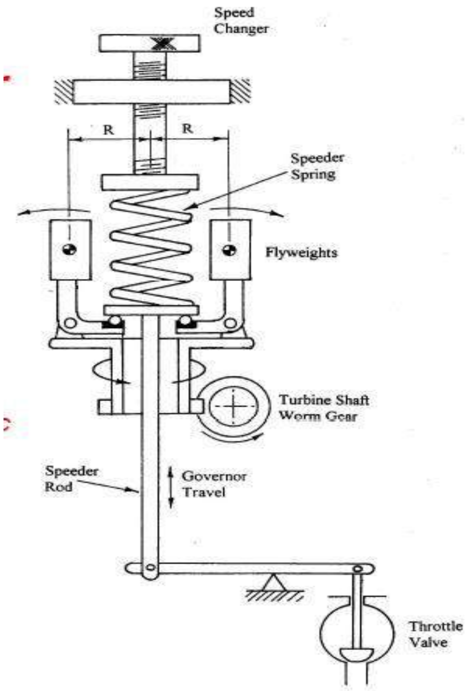
- **FACTORS BLADE FAILURES**
  1. Unknown 26%
  2. Stress-Corrosion Cracking 22%

3. High-Cycle Fatigue 20%
4. Corrosion-Fatigue Cracking 7%
5. Temperature Creep Rupture 6%
6. Low-Cycle Fatigue 5%
7. Corrosion 4%
8. Other causes 10%
9. Besides, many damage mechanisms operate in combination of
   a. poor steam/water chemistry,
   b. certain blade design factors that vary from one turbine manufacture to other,
   c. system operating parameters,

- **How is the washing of turbine blades carried out with the condensate?**
  1. The washing is carried out with the condensate at 100°C.
  2. The turbine is cooled or heated up to 100°C and filled with the condensate via a turbine drain.
  3. The rotor is turned or barred by hand and the condensate is drained after 2 to 4 hours.
  4. It is then again filled with the condensate at 100°C (but up to the rotor center-level), the rotor is rotated and the condensate is drained after sometime. This process is repeated several times.
- **How is turbine blade washing with wet steam carried out?**
  1. Wet steam produced usually by injecting cold condensate into the superheated steam, is introduced to the turbine which is kept on running at about 20% of nominal speed.
  2. For backpressure turbine the exhaust steam is let out into the open air through a gate valve. For a condensing turbine, the vacuum pump is kept out of service while cooling water is running, with the effect that the entering cooling steam is condensed. The condensate is drained off.
  3. The washing steam condition is gradually adjusted to a final wetness of 0.9 to 0.95.
     **Note, it is important:**
     - ✓ Not to change washing steam temperature by 10°C/min,
     - ✓ To keep all turbine cylinder drains open.
- **How is oil pressure maintained when starting or stopping a medium-sized turbine?**
  An auxiliary pump is provided to maintain oil pressure. Some auxiliary pumps are turned by a hand crank; others are motor-driven. This pump is used when the integral pump is running too slowly to provide pressure, as when starting or securing a medium-sized turbine.
- **How many types of particle-impact damage occur in turbine blades?**
  1. Erosion/corrosion.
  2. Foreign-particle impacts.
  3. Solid-particle erosion.
  4. Water damage.
- **How to prevent turbine deposition?**
  By upgrading the quality of steam. That is by ensuring proper:
  1. Boiler feed water quality.
  2. Steam boiler model.
  3. Boiler design.
  4. Boiler operation.

- **How is a fly ball governor used with a hydraulic control?**


NORMAL SPEED
FLYWEIGHTS
BUFFER PISTON
HIGH PRESSURE OIL FLOW BLOCKED
OIL TRAPPED UNDER BUFFER PISTON
OVERSPEED
HIGH PRESSURE OIL FLOW BLOCKED
TRAPPED OIL BLEEDS OFF SPRING DEPRESS
BUFFER PISTON
UNDERSPEED
HIGH PRESSURE OIL FLOW TO BUFFER PISTON
OIL PRESSURE BUFFER PISTON SPRING


Speed Changer
R
R
Speeder Spring
Flyweights
Turbine Shaft Worm Gear
Speeder Rod
Governor Travel
Throttle Valve

As the turbine speeds up, the weights are moved outward by centrifugal force, causing linkage to open a pilot valve that admits and releases oil on either side of a piston or on one side of a spring-loaded piston. The movement of the piston controls the steam valves.

- **The consequences of turbine depositions have three effects?**
  1. Economic Effect:
     a. Reduction in turbine output
     b. Decrease in efficiency requiring higher steam consumption.
  2. Effect of Overloading and Decreasing Reliability in Operation:
     a. Pressure characteristic in the turbine gets disturbed with the effect that thrust and overloading of thrust bearing increase.
     b. Blades are subjected to higher bending stresses.
     c. Natural vibrations of the blading are affected.
     d. Vibration due to uneven deposition on turbine blading.
     e. Valve jamming due to deposits on valve stems.
  3. Corrosion Effect:
     a. Fatigue corrosion.
     b. Pitting corrosion.
     c. Stress corrosion.
- **What are the losses in steam turbines?**
  1. **Residual Velocity Loss** - This is equal to the absolute velocity of the steam at the blade exit.
  2. **Loss due to Friction -** Friction loss occurs in the nozzles, turbine blades and between the steam and rotating discs. This loss is about 10%.
  3. Leakage Loss.
  4. **Loss due to Mechanical Friction** - Accounts for the loss due to friction between the shaft and bearing.
  5. **Radiation Loss** - Though this loss is negligible, as turbine casings are insulated, it occurs due to heat leakage from turbine to ambient air which is at a much lower temperature than the turbine.
  6. **Loss due to Moisture -** In the lower stages of the turbine, the steam may become wet as the velocity of water particles is lower than that of steam. So a part of the kinetic energy of steam is lost to drag the water particles along with it.
- **What are the possible causes for the turbine not running at rated speed?**
  1. The possible causes are:
     a. too many hand valves closed,
     b. oil relay governor set too low,
     c. inlet steam pressure too low or exhaust pressure too high,
     d. load higher than turbine rating,
     e. throttle valve not opening fully,
     f. safety trip valve not opening properly,
     g. nozzles plugged,
     h. steam strainer choked.
- **What are the possible causes of a governor not operating?**
  1. Restriction of throttle valve reflex.
  2. Failure of governor control on start-up.

  If it is found that after start-up, the speed increases continuously and the governor is not closing the throttle valve, it may be that the governor pump has been installed in the wrong direction.
- **What are the possible causes of excessive vibration or noise in a steam turbine?**
  1. Misalignment.
  2. Worn bearings.
  3. Worn coupling to driven machine.
  4. Unbalanced coupling to driven machine.
  5. Unbalanced wheel.
  6. Piping strain.
  7. Bent shaft.
- **What are the possible causes of the speed of the turbine rotor increasing excessively as the load is decreased?**
  1. Throttle valve not closing fully.
  2. Wearing of throttle valve seats.
- **What are the stresses to which a steam turbine rotor is subjected during its service life?**
  1. **Mechanical stress** - The factors that contribute to mechanical stress in the shaft are the centrifugal forces and torque's generated due to revolving motion of the shaft as well as bending arising during steady-state operation.
  2. **Thermal stress** - Transient operating phases i.e. startup and shutdown the genesis of thermal stress induced to the turbine shaft.
  3. **Electrically induced stress** - They originate due to short circuits and faulty synchronization.

- **What are topping and superposed turbines?**

  Topping and superposed turbines are high-pressure, non-condensing units that can be added to an older, moderate-pressure plant. Topping turbines receive high-pressure steam from new high-pressure boilers. The exhaust steam of the new turbine is at the same pressure as the old boilers and is used to supply the old turbines.

- **What factors are responsible for turbine-blade failures?**
    1. In the high pressure cylinder, the turbine blades are mostly affected by:
    a. solid-particle erosion (SPE),
    b. high cycle fatigue,
    2. Whereas in the last few stages of the low-pressure cylinder, the blade damage is mainly afflicted by:
    a. erosion,
    b. corrosion,
    c. stress /fatigue damage mechanism.
    d. According to EPRI (Electric Power Research Institute, USA) data stress-corrosion cracking and fatigue are the chief exponents for turbine-blade failures in utility industries.
- **What factors cause excessive steam leakage under carbon rings?**
    1. Dirt under rings. - Steam borne scale or dirt foul up the rings if steam is leaking under the carbon rings.
    2. Shaft scored.
    3. Worn or broken carbon rings.

  These should be replaced with a new set of carbon rings. The complete ring is to be replaced.
- **What factors contribute to excessive speed variation of the turbine?**
    1. Improper governor droop adjustment.
    2. Improper governor lubrication.
    3. Throttle assembly friction.
    4. Friction in stuffing box.
    5. High inlet steam pressure and light load.
    6. Rapidly varying load.

- **What types of deposits are formed on steam turbine blading?**
    1. Water-soluble deposits.
    a. NaCl, $Na_2SO_4$, NaOH and $Na_3PO_4$
    2 Water-insoluble deposits.
    a. $SiO_2$ (mainly).

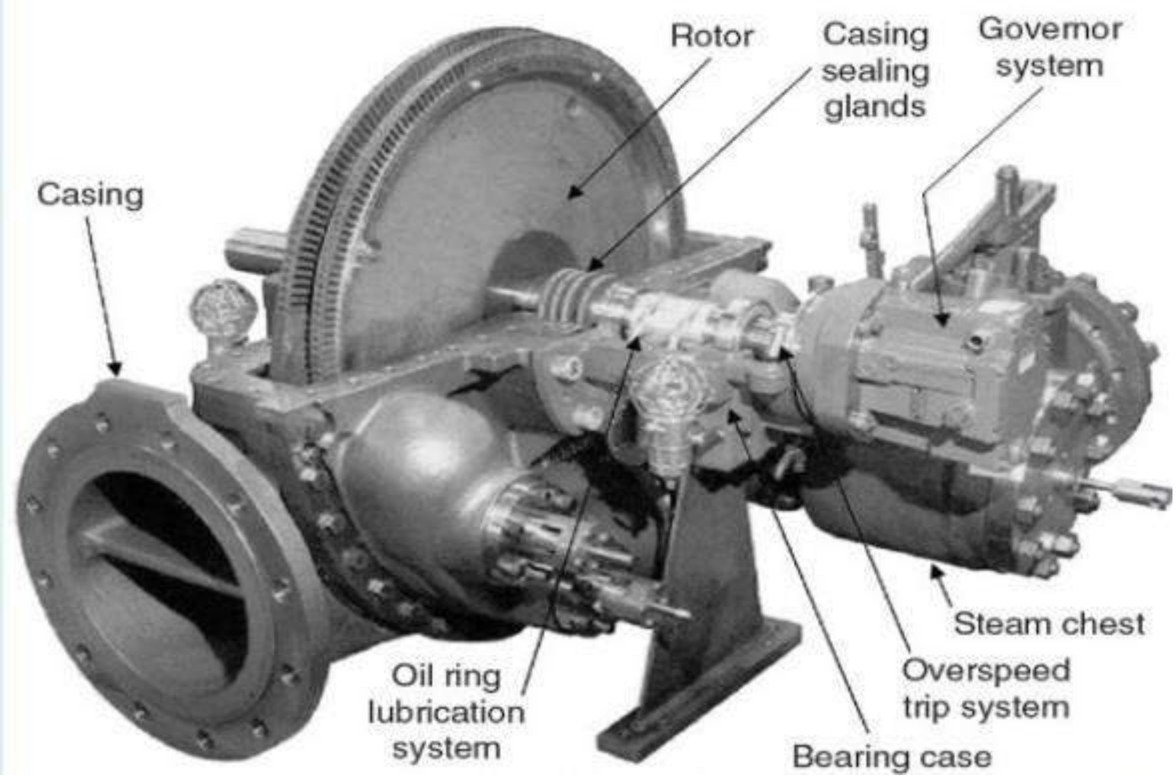
## • Small steam turbine :

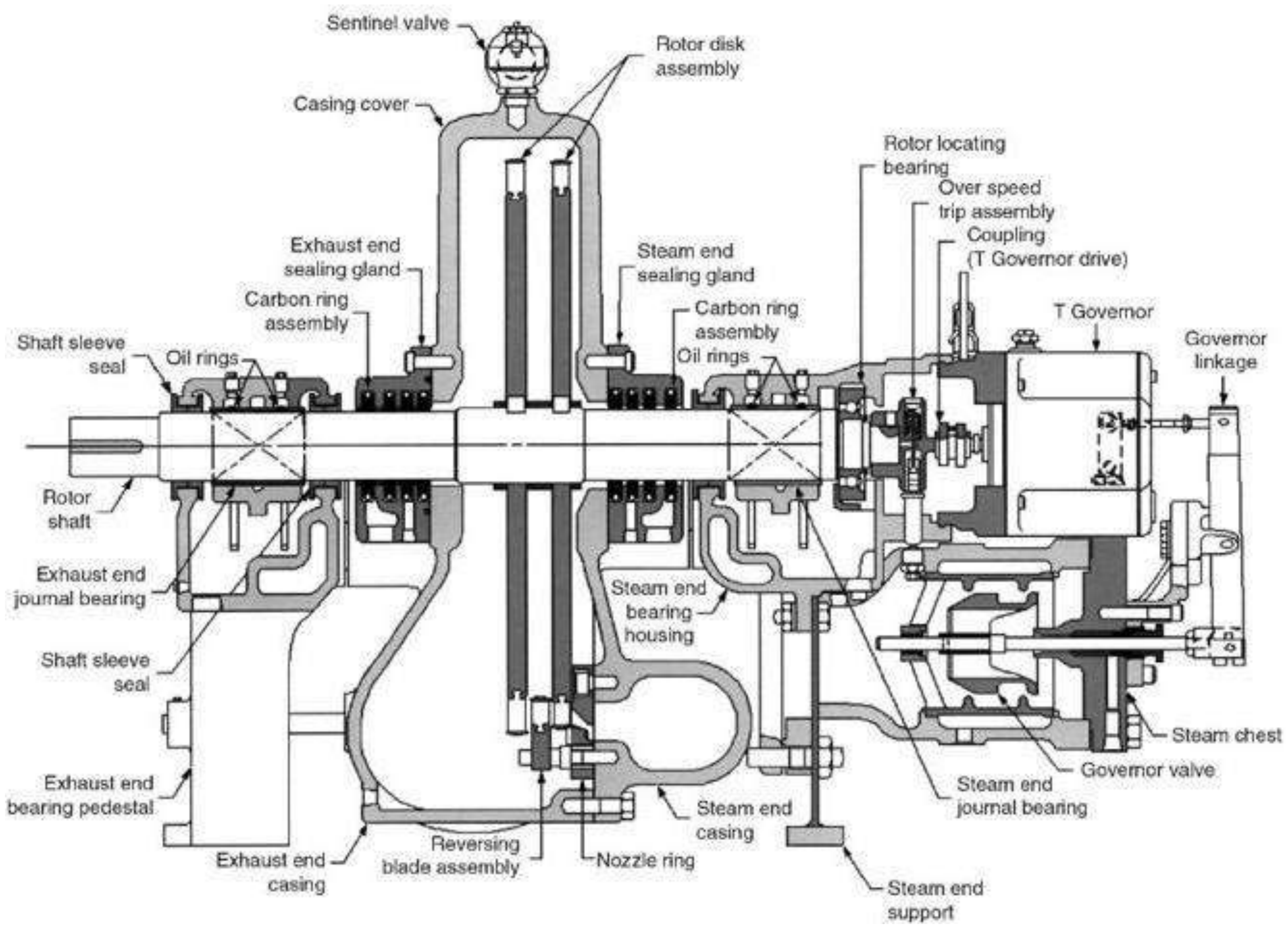
### Turbine Casings

The casing shape and construction details depend on whether it is a High Pressure(HP) or Low Pressure (LP) casings. For low and moderate inlet steam pressure up to 120 bar, a single shell casing is used. With a rise in inlet pressure the casing thickness as to be increasing. Handling such heavy casing is very difficult also the turbine as to slowly brought up to the operation temperature. Otherwise undue internal stress or distortions to the thick casing may arise. To over this for high pressure and temperature application double casing is used. In the double casing inner casing is for High pressure and the outer casing is for hold the low pressure.

Most of the turbines have casings with horizontal split type. Due to horizontal split it easy for assembling and dismantling for maintenance of turbine. Also, maintain proper axial and radial clearance between the rotor and stationary parts.

Usually, the turbine casings are heavy in order to withstand the high pressures and temperatures. It is general practice the thickness of walls and flanges decrease from the inlet to exhaust end due to the decrease in steam pressure from inlet to exhaust.




Sentinel valve
Rotor disk assembly
Casing cover
Rotor locating bearing
Over speed trip assembly
Coupling (T Governor drive)
Exhaust end sealing gland
Steam end sealing gland
Carbon ring assembly
Carbon ring assembly
Oil rings
T Governor
Governor linkage
Shaft sleeve seal
Oil rings
Rotor shaft
Exhaust end journal bearing
Steam end bearing housing
Shaft sleeve seal
Steam chest
Governor valve
Exhaust end bearing pedestal
Steam end journal bearing
Steam end casing
Reversing blade assembly
Exhaust end casing
Nozzle ring
Steam end support

### Turbine Casing MOC

Large casings for low-pressure turbines are of welded plate construction, while smaller L. P. casings are of cast iron, which may be used for temperatures up to 230°C.

Casings for intermediate pressures are generally of cast carbon steel able to withstand up to 425°C. The high-temperature high-pressure casings for temperatures exceeding 550°C are of cast alloy steel such as 3 Cr 1Mo (3% Chromium + 1% Molybdenum.) The turbine casings are subjected to maximum temperatures and under constant pressure. Hence the material of casing shall subject high “Creep”. The casing joints are made of steam tight by matching the flange faces very exactly and very smoothly, without the use of gaskets. Dowel pins are used to secure exact alignment of the casing flange joints. The casing contains grooves for fixing the diaphragms (for impulse turbines) or for the stationary blades (reaction turbines).

### Turbine Rotors

The steam turbine rotors must be designed with the most care as it is mostly the highly stressed component in the turbine. The design of a turbine rotor depends on the operating principle of the turbine.

The **impulse turbine,** in which the pressure drops across the stationary blades. The stationary blades are mounted in the diaphragm and the moving blades fixed or forged on the rotor. Steam leakage is in between the stationary blades and the rotor. The leakage rate is controlled by labyrinth seals. This construction requires a disc rotor.

The **reaction turbine** has pressure drops across the moving as well as across the stationary blades. The disc rotor would create a large axial thrust across each disc. Hence disc rotors are not used in the reaction turbine. For this application, a drum rotor is used to eliminate the axial thrust caused by the discs, but not the axial thrust caused by the differential pressure across the moving blades. Due to this, the configuration of reaction turbine is more complicated.

### Disc Type Rotors

This type of rotor is largely used in steam turbines. The disc type rotors are made by forging process. Normally the forged rotor weight is around 50% higher than the final machined rotors.

### Drum Type Rotors

Initially, the reaction turbines rotors are made by solid forged drum-type rotor. The rotors are heavy and rigid construction. Due to this, the inertia of the rotor is very high when compare with the disc-type rotor of the same capacity. To overcome this nowadays the hollow drum-type rotors are used instead of solid rigid rotors. Usually, this type of rotor is made of two pieces construction. In some special cases, the rotor is made up of multi-piece construction. The drums are machined both outside and inside to get perfect rotor balance.

### Turbine Blades

The efficiency of the turbine depends on more than anything else on the design of the turbine blades. The impulse blades must be designed to convert the kinetic energy of the steam into mechanical energy. The same goes for the reaction blades, which furthermore must convert pressure energy to kinetic energy.

**The blades are strong enough to withstand the following factors**

- High temperatures and stresses due to the pulsating steam load
- Stress due to centrifugal force

- Erosion and corrosion resistance.

Depend upon the pressure region the blades are also classified as follow.

- High Pressure (HP) blades
- Intermediate Pressure (IP) blades
- Low Pressure (LP) blades

The turbine blades are made up of chromium-nickel steel or 17 Cr'13 Ni – steel.

**Stationary Blades (Diaphragms) and Nozzles**

**Nozzle:**

Nozzles are used to guide the steam to hit the moving blades and to convert the pressure energy into the kinetic energy. In the case of small impulse turbine, the nozzles are located in the lower half of the casing. But in the case of the larger turbine, the nozzles are located on the upper half of the casing.

Stationary Blades (Diaphragms)

All stages following the control stage have the nozzles located in diaphragms. The diaphragms are in halves and fitted into grooves in the casing. Anti-rotating pin or locking pieces in the upper part of the casing prevent the diaphragm to rotate.

All modern diaphragms are of an all-welded construction. The stationary blades in reaction turbines are fitted into grooves in the casing halves; keys as shown lock the blades in place. In some cases, the blades have keys or serration on one side of the root and a caulking strip on the other side of the root is used to tighten the blades solidly in the grooves.

**Blade Fastening:**

After turbine blades are machined through the milling process. Then the blades are inserted in the rotor groove. Depend upon the application the blade root section varies

Blade roots are subject to take four types of stress

- Tensile stress due to the centrifugal forces
- Bending stress due to fluid forces act on the blade in tangential direction
- Stress due to vibration forces.
- Thermal stress also due to the uneven heating of the blade root and the rim.

**Twisted Blades**

This type of blades is used in the last stage of a large multistage steam turbine. These are the largest blade in turbine and contribute around 10% of the turbine total output. Due to larger in size, these types of blades are subjected to high centrifugal and bending forces. To overcome these forces twisted construction is used.

**Shrouds**

Shrouds are used to reinforce the turbine blades free ends to reduce vibration and leakage. This is done by reverting a flat end over the blades refer figure. In some cases especially at the early stages, the shroud may be integral with the blade. When the blades are very long as in the case of the last stage of LP turbine. The rotor blades are further reinforced by using lacing wires (caulking wire) which circumferentially connects all the blades at a desired radius and shrouding is eliminated.

**Turbine Barring device**

When a turbine is left cold and at standstill, the weight of the rotor will tend to bend the rotor slightly. If left at the standstill while the turbine is still hot, the lower half of the rotor will cool off faster than the upper half and the rotor will bend upwards "hog". In both cases, the turbine would be difficult if not impossible to start up. To overcome the problem the manufacturer supplies the larger turbines with a turning or barring gear consisting of an electric motor which through several sets of reducing gears turns the turbine shaft at low speed.

The first turning gears turned the shaft at approximately 20 rev/mm, later increased to 40 and up to 60 rev/mm as proper lubrication is difficult to obtain at low speed. Some turning gears, electric or hydraulic, turn the shaft at set times over a period of 24 hours. Before a cold turbine is started up it should be on the barring gear for approximately three hours. When a turbine is shut down, it should be barring for the next 24 hours.

**Turbine Bearings**

One of the steam turbine basic parts is bearing. They are two types of bearings used based on the type of load act on them

- Radial Bearing
- Thrust Bearing

**Radial Bearings**

For small turbines mostly equipped with anti-friction type bearings. Widely used anti-friction bearings are the self-aligning spherical ball or roller bearing with flooded type lubrication is used.

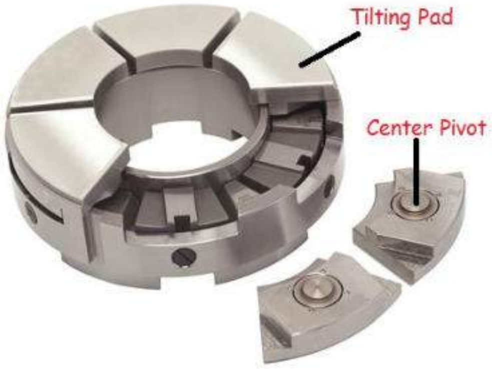
In the case of medium turbines used plain journal bearing. They may be ring lubricated sleeve bearings with bronze or Babbitt lining. Both flooded and force types are employed.

For larger turbines, the radial bearing will be a tilting pad type. The number of pad per bearing will be selected based on the weight of the rotor. For these types of bearing forced lubrication is used.

**Thrust Bearings**

The main two purposes of the thrust bearing are:

- To keep the rotor in an exact position in the casing.
- To absorb axial thrust on the rotor due to steam flow.



The thrust bearing is located on the free end of the rotor or we can say at the steam inlet of the turbine. The axial thrust force is very small for impulse turbines. This is due to the presence of pressure equalizing holes in the rotor discs to balance the thrust force generated across the disc. A simple thrust bearing such as a ball bearing for small turbines and radial babbitt facing on journal bearings are commonly used in small and medium-size turbines. Tilling pad type thrust bearings are used in the large steam turbines.

In the case of reaction turbine, the pressure drop across the moving blades creates a heavy axial thrust force in the direction of steam flow through the turbine. Due to greater thrust force, the heavy duty thrust bearing such as tilting pad type thrust bearings are used. The axial thrust in reaction turbines can be nearly reduced by the using off balance or dummy pistons.

As we seen the purpose, the thrust bearing not only taking the thrust load and also to maintain the position of the rotor. The axial position of the rotor is very important and an axial position indicator is often applied to the thrust bearing. As a normal practice, the axial position of rotor exceeds 0.3 mm alarm and shutdown at 0.6 mm.

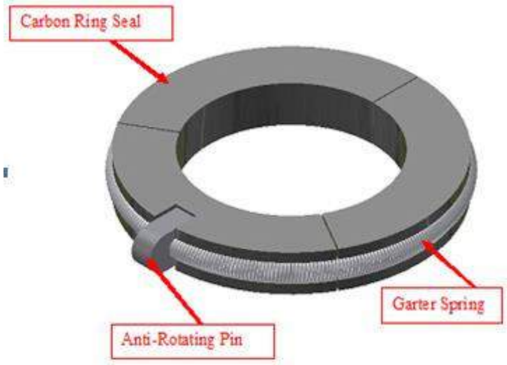
**Turbine Seals**

Seals are used to reduce the leakage of steam between the rotary and stationary parts of the steam turbine. Depend upon the location of seal, the seals are classified as two types, they are

- Shaft Seal
- Blade Seal

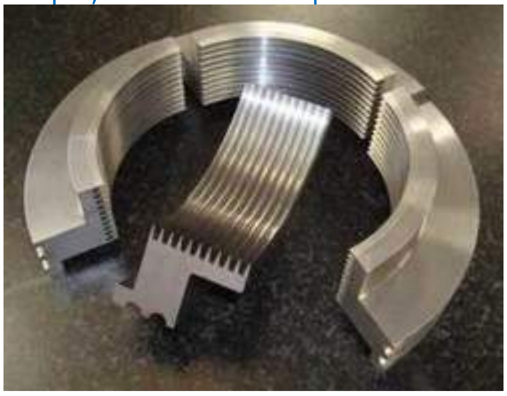
**Shaft Seals**

Shaft seals are used to prevent the steam leakage where the shafts extend through the casing. In the case of a small turbine (as per API 611) carbon rings are used as shaft seal up to the surface speed of the shaft is 50m/s. The carbon ring is made up of three segments butting together tightly under the pressure of a garter spring. The carbon rings are free floating in the housing and an anti-rotating pin is used to prevent the rotation of carbon ring seal. Due to the self-lubrication properties of the carbon rings, they maintain a close clearance with the shaft. For larger steam turbines (as per API 612) labyrinth seal are used as shaft seals. In the case of condensing steam turbine to prevent the air ingression at the shaft seal by Gland condenser and ejector arrangements (as per API 612).



### Blade Seals

Blade seals are used to prevent the steam leakage between the diaphragm and the shaft. The efficiency of the turbine depends largely on the blade seals. Labyrinth seals are used as blade seals in the small and large turbines. In the case of large steam turbine spring loaded labyrinth seals are used. The seals are made up of brass or stainless steel. Also, the sharp edge gives better sealing and rubs off easily without excessive heating in case of a slightly eccentric shaft. Some labyrinth seals are very simple, others are complicated.



### Turbine Couplings

The purpose of couplings is to transmit power from the prime mover to the driven piece of machinery. Flexible type couplings are used in turbines. The coupling hubs are taper bore and key way to fit the tapered end of the shaft.

### Governor

The governor is one of the steam turbine basic parts. Its main function is to control the operation of a steam turbine. Generally, the governor is classified as two types

- Speed-sensing governor
- Pressure sensing or load governor

### Speed Sensing Governor

Speed-sensing governors are used in power generation application to maintain a constant speed with respect to the load change in governor. Droop is one of the important characteristics of this governor selection.

### Pressure sensitive governor

These are applied to back pressure and extraction turbines in connection with the speed sensitive governor.

### They are three types of governor used in steam turbine

- Mechanical Governor
- Hydro-mechanical Governor
- Electronic Governor

In the case of small turbine Oil relay type (Hydro-mechanical) governor NEMA class “A” is used. For the larger turbine, electronic governor NEMA class “D” is used.

### Lubrication System

Oil flood lubrication is used for small turbines and pressurized lubrication is used for larger turbines. The pressurized lubrication system consists of lube oil tank, oil pump, filter, cooler, pressure regulating valve, etc., The pressurized lubrication system of turbine shall be as per API 614.

## Steam turbine normal maintenance plan:

### Daily maintenance

❏ Monitor bearing housing oil levels, refill as needed

❏ Monitor and record: ❍ Lube, seal, and control oil pressures and temperatures ❍ Bearing metal temperatures ❍ Bearing case or bearing oil throw off temperatures ❍ Cooling water conditions ❍ Bearing housing vibration levels: vertical & horizontal ❍ 1st stage pressure (if applicable) ❍ Inlet steam pressure and temperature at flanges ❍ Steam flow rates ❍ Exhaust steam pressure and temperature at flanges ❍ Governor valve/ position ❍ Speed ❍ Load ❏ Walk-around inspection for unusual noises and leaks ❏ Check boiler feed-water quality

### Weekly maintenance

❏ Check for steam leaks

### Monthly and Semi-Annual Inspections

Bearing Inspections & Minor Overhauls Steam turbine bearings and seals should be physically inspected every two to three years. This entails opening the bearing housings; removing and inspecting the bearings and seals; and replacing any components as needed.

❏ Send oil sample to lab for analysis (if gearbox)

**Annual inspection** The annual inspection is also helpful for planning of minor and major overhauls. ❏ Visual inspection of seal and bearing housings, and drain piping for wear, leaks, vibration, and plugged filters. Housings are not opened unless a potential problem is detected. ❏ Visual, mechanical, and

electrical inspection of all instrumentation, protection, and control systems, including trip assemblies ❑ Check safety devices ❑ Over speed the turbine to check the over speed trip
Visually inspect the turbine generator string for: ❍ Evidence of steam, oil or water leakage ❍ Evidence of steam deposits ❍ Proper position of all valves ❍ Proper oil level ❍ Condition of all control and trip linkages ❍ Condition of instrumentation, conduit, wiring, insulation, etc. ❑ Review the recorded of number of normal starts and stops ❑ Review the record of unit trip outs and the reasons ❑ Review the record of oil samples and conditioning ❑ Review the record of operating data: pressure, temperatures, vibration, etc. ❑ Discuss operating problems experienced since last inspection or repair ❑ Grease generator bearings (if applicable) ❑ Inspect spare parts inventory

### Bearing inspection & minor overhaul

Turbine Scope of Work
❑ Shutdown equipment ❑ Lock Out Tag Out unit ❑ Visually inspect the turbine generator string for: ❍ Evidence of steam, oil or water leakage ❍ Evidence of steam deposits ❍ Proper position of all valves ❍ Condition of all control and trip linkages ❍ Condition of instrumentation, conduit, wiring, insulation, etc. ❑ Measure and record turbine axial thrust float and radial lift ❑ Disassemble and inspect turbine bearings for: ❑ Visual condition of shaft journals ❑ Journal bearing clearance and condition ❑ Oil seal clearances ❑ Condition of carbon rings or labyrinth seals; replace if necessary ❑ Visually inspect governor and trip valve ❑ Inspect governor valve and valve seat for signs of leakage Hand lap the valve if signs of uneven wear exist ❑ Replace the governor valve stem packing, if necessary ❑ Check governor valve setting; adjust open, closed and span, as necessary ❑ Check trip valve setting and linkage; adjust as necessary ❑ Check and clean water cooling chamber (if applicable) ❑ Clean and inspect trip valve for signs of leakage ❑ Replace worn parts and hand lap if necessary ❑ Check shaft alignment ❑ Remove and clean steam strainer. If strainer is exceptionally dirty, clean every six months

### Major overhaul

A major overhaul is a detailed inspection and overhaul of the entire steam turbine generator set including the turbine casing, rotor, seals, and bearings; the generator; and auxiliaries such as the gear, couplings, lubrication system and controls. should be overhauled every 5 years

Turbine Scope of Work ❑ Perform same scope as bearing inspection and minor overhaul ❑ Remove upper half casing and record "as found" internal clearances ❑ Remove rotor and perform visual inspection ❑ Check condition of labyrinth seals; replace if necessary ❑ Hand clean nozzle ring and visually inspect in position ❑ Visually inspect reversing buckets & diaphragms ❑ Disassemble, inspect, and reassemble main stop valve, if applicable ❑ Dimensional inspection of rotor journal bearings and seal areas ❑ Check shaft alignment ❑ Drain oil reservoir and lube oil coolers ❍ Inspect oil coolers ❍ Clean oil reservoir ❍ Refill oil reservoir ❑ Install screens before bearing housings; flush oil using system pumps and filters
**Refer: API 611 /612**

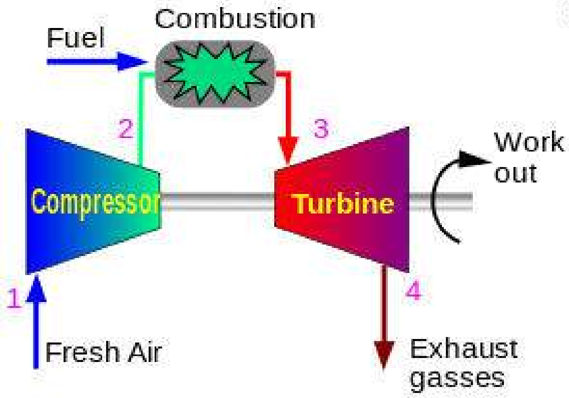
- **Gas turbine: API 616**

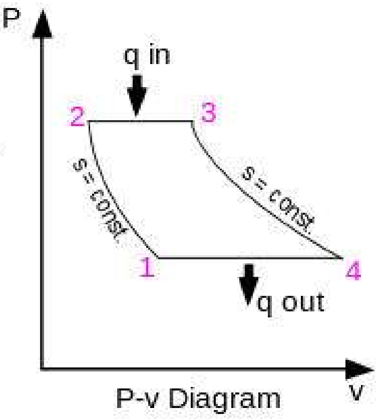
### What is a Gas Turbine?

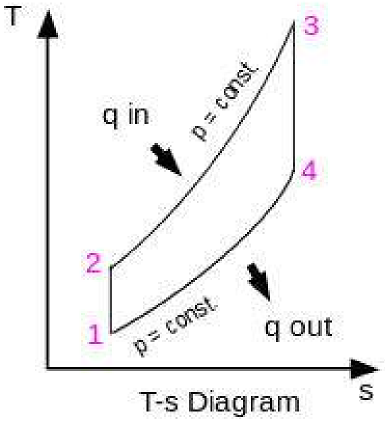
Gas Turbine is a turbomachine that extracts energy from a fluid flow and converts it into mechanical energy (work).
A gas turbine has an upstream rotating compressor coupled to a downstream turbine, and a Combustion chamber (combustor) in-between.
The working fluid enters an inlet duct and continues to the compressor. The compressor pressurizes the fluid/gas and will also lead to an increase in temperature. By combustion of fuel in the combustion chamber, energy is added to the working fluid. The working fluid which now has a temperature of about 1200-1450°C enters the last stage in the process, the turbine. Here the fluid expands and thus transferring its energy to the turbine blade in form of mechanical work.

**Gas Turbine Performance Characteristics** ▪ The conversion of thermal into mechanical energy occurs in two-steps: • The axial flow compressor compresses its working fluid by first accelerating the fluid and then diffusing it to obtain a pressure increase. The fluid is accelerated by the rotating blades-rotor, and then diffused in the stationary blades-stator. • The rotor impacts kinetic energy • The stator recovers kinetic energy as pressure and redirects the flow to the next stage at right angle. ▪ The compressor normally requires from 55 to 67% of the total work developed by the turbine
It takes the air from atmosphere compresses it to sufficiently high pressure, same pressurized air is then utilized for combustion, which takes place by in combustion chamber by addition of fuel , there by hot combustion products are generated which are expanded in the turbine where Heat energy of hot combustion products is converted in to mechanical energy of shaft which in turn utilized for generating power in Generator. Compression is carried out by Axial Flow compressor , Heat addition is done by

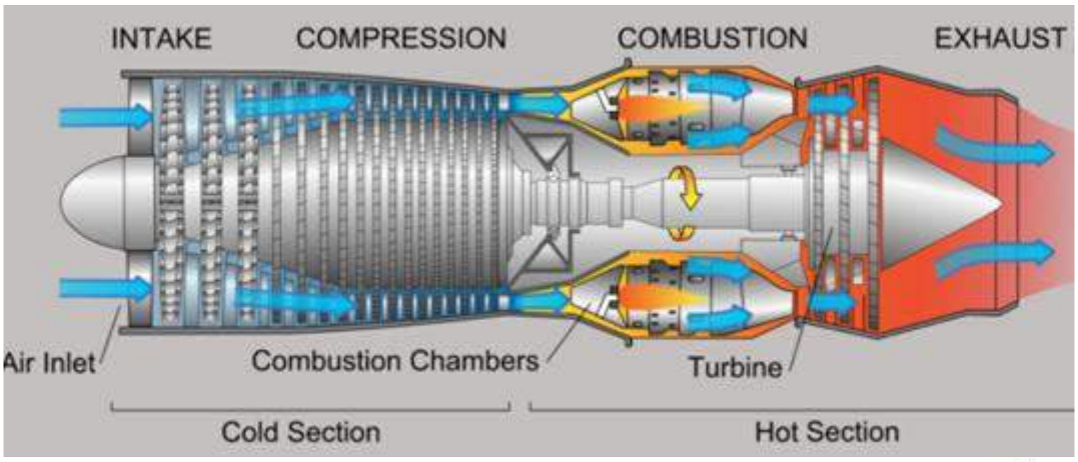
Fuel in combustion chambers , Expansion of hot combustible gases is carried out in Turbine and Burnt Gases are exhausted to atmosphere or utilized for steam generation in GTs. All of these four processes are carried out in Only one Factory assembled Unit which is called Gas Turbine. Drawing shows the Typical Brayton cycle and also shows the components of Gas Turbine. Gas Turbine operates on Brayton Cycle. Brayton cycle is having divided in four segments namely Compression, Heat addition, Expansion and Exhaust. Process is explained in following diagram on T-S curve.

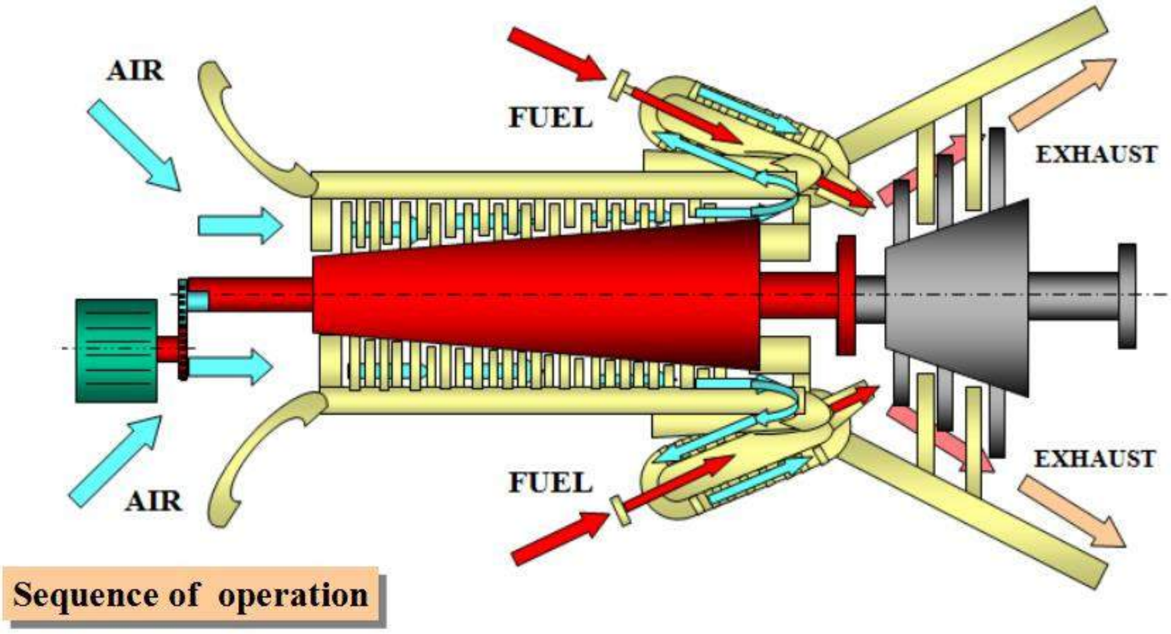

Fuel
Combustion
2
3
Work out
Compressor
Turbine
1
4
Fresh Air
Exhaust gasses


P
q in
2
3
s = const.
s = const.
1
4
q out
P-v Diagram
v


T
3
q in
p = const.
4
2
1
p = const.
q out
T-s Diagram
s

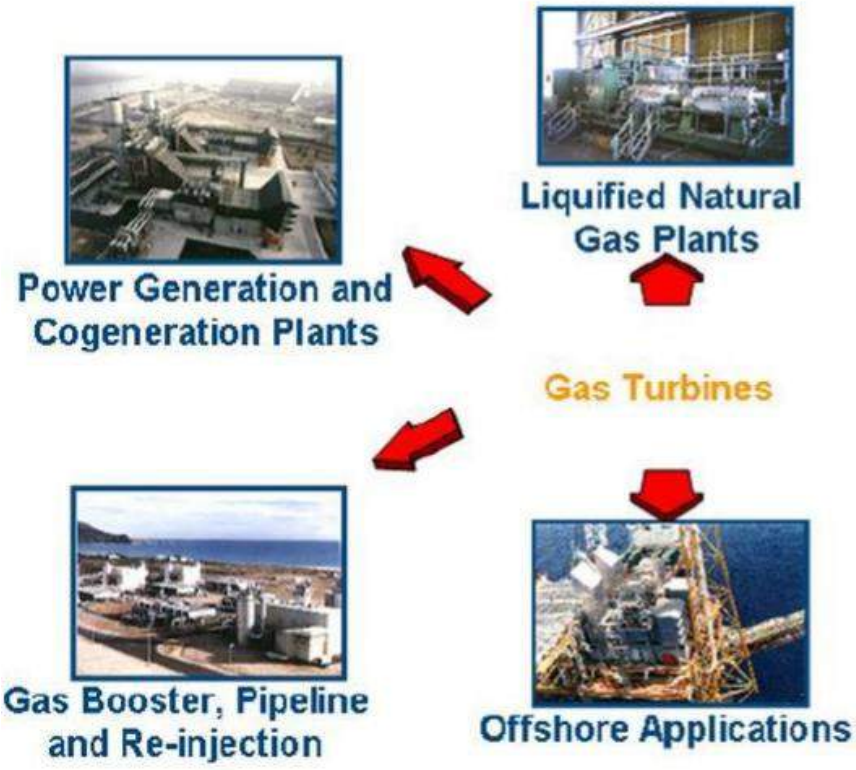
**Gas Turbine Components** ▪ Compressor • Draws in air & compresses it ▪ Combustion Chamber • Fuel pumped in and ignited to burn with compressed air ▪ Turbine • Hot gases converted to work • Can drive compressor & external load


INTAKE
COMPRESSION
COMBUSTION
EXHAUST
Air Inlet
Combustion Chambers
Turbine
Cold Section
Hot Section


AIR
FUEL
EXHAUST
EXHAUST
FUEL
AIR
Sequence of operation

**Gas Turbine had a following advantages** • Capital cost is less . • Fewer auxiliaries. • Less erection time. • Less area. • Higher thermal efficiency when operated in combined cycle mode. • Quick start. • Fuel flexibility ( Liquid / Gas ) • Very compact system. • Black start facility. • Suitable for Base load / Peak load / Part load operation. No/Less environmental Hazards. • Control reliability

## Gas turbine application


Liquified Natural Gas Plants
Power Generation and Cogeneration Plants
Petrochemical Plants
Gas Turbines
Gas Booster, Pipeline and Re-injection
Offshore Applications
District Heating

GE offers a range of gas turbines, ranging from 11 to 340 megawatts.

Siemens gas turbine product line covers the range from 5 MW to 400 MW.

MHI provides a range of gas turbines, from 6MW to 300MW.

Alstom offers a range of gas turbines, ranging from 113 MW to 326 MW

### External Factors Affecting Gas Turbine Performance

A gas turbine uses atmospheric air, therefore, its performance is greatly affected by all factors that influence the weight flow rate of air delivered to the compressor. These factors are: • Ambient Temperature • Ambient Pressure • Relative humidity .

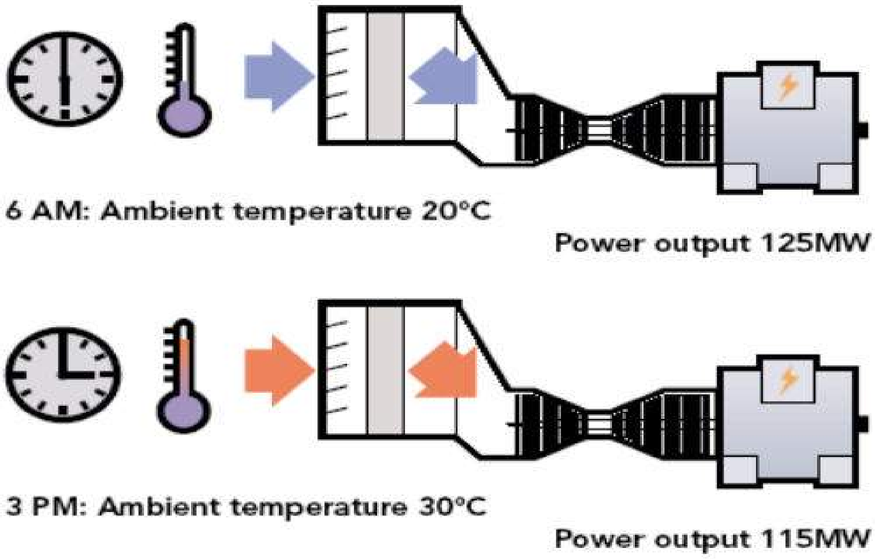
### External Factors Affecting Gas Turbine Performance – Ambient Temperature

A gas turbine is a constant volume machine i.e. the volume of air compressed is fixed. Large gas turbines have airflows rates as high as 680 Kg/Sec. At sea level and at 15 °C, air has a density of approximately 1.225 kg/m3. 21% of the air is oxygen (O2)

If $T_{amb}$ ⇑ ⇨

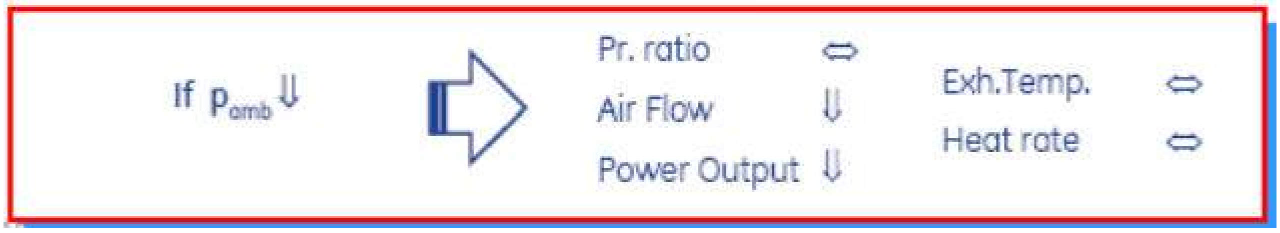
Press. ratio ⇓
Air Flow ⇓
Power Output ⇓

Exh. Temp. ⇑
Heat rate ⇑


6 AM: Ambient temperature 20°C
Power output 125MW
3 PM: Ambient temperature 30°C
Power output 115MW

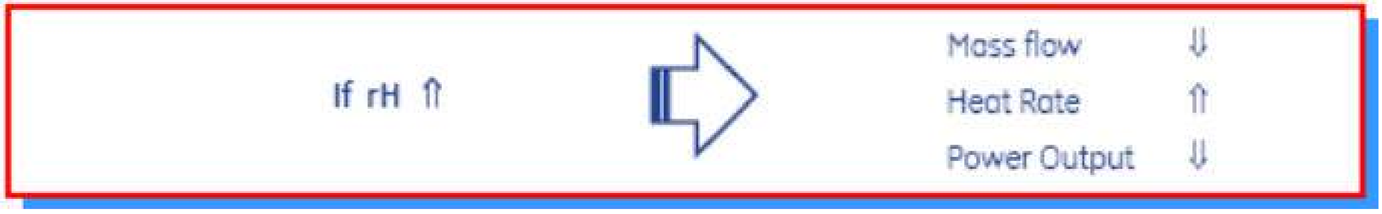
**External Factors Affecting Gas Turbine Performance – Ambient Pressure**

If the atmospheric pressure decreases, the weight flow rate of air decreases (because of a reduction in its specific weight) and useful power is proportionally reduced being proportional to the weight flow rate of gas.

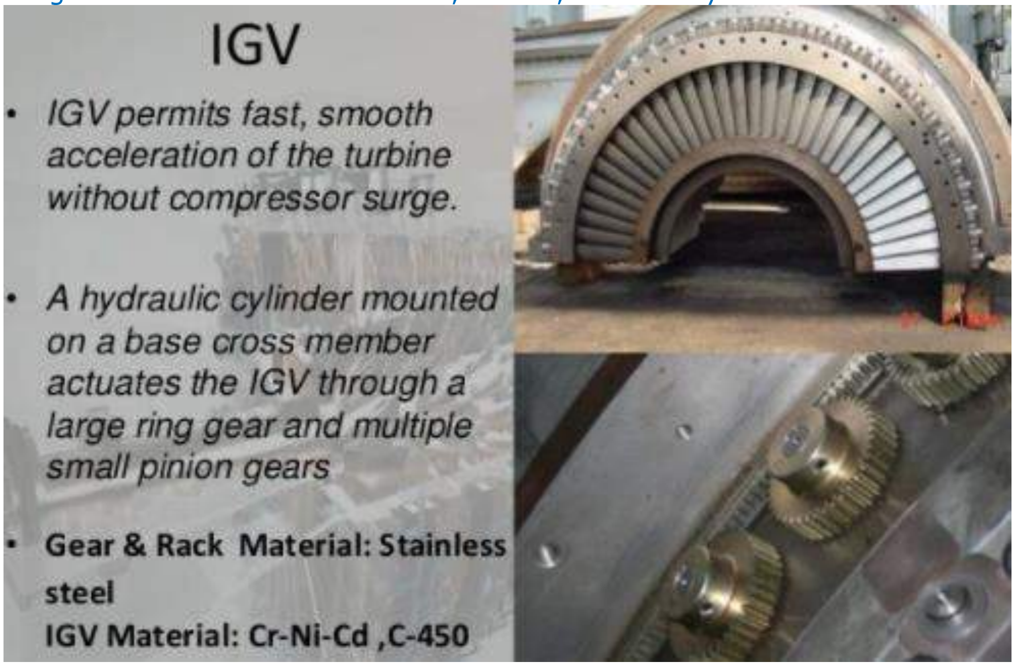

If $p_{amb}$ ⇓
Pr. ratio ⇔
Air Flow ⇓
Power Output ⇓
Exh.Temp. ⇔
Heat rate ⇔

**External Factors Affecting Gas Turbine Performance – Relative Humidity**

Relative humidity is a term used to describe the amount of water vapor in a mixture of air and water vapor. In fact, humid air is less dense than dry air. Relative humidity influences the specific weight of compressor inlet air, so if the relative humidity increases, the power output decreases and heat rate (HR) increases.


If rH ⇑
Mass flow ⇓
Heat Rate ⇑
Power Output ⇓

Dry air contains about 78% nitrogen (N2) molecules, which each have a molecular weight of 28 (2) atoms with atomic weight (14). Another 21% of the air is oxygen (O2), with each molecule having a molecular weight of 32 (2 atoms with atomic weight 16). Water (H2O) vapor molecules, which are one oxygen atom with a weight of 16 and two hydrogen atoms each with a weight of 1, add up to a molecular weight of 18, which is much lighter than the nitrogen and oxygen they displace when they evaporate into air. In other words, replacing nitrogen and oxygen with water vapor decreases the weight of the air in the cubic foot; that is, it's density decreases.

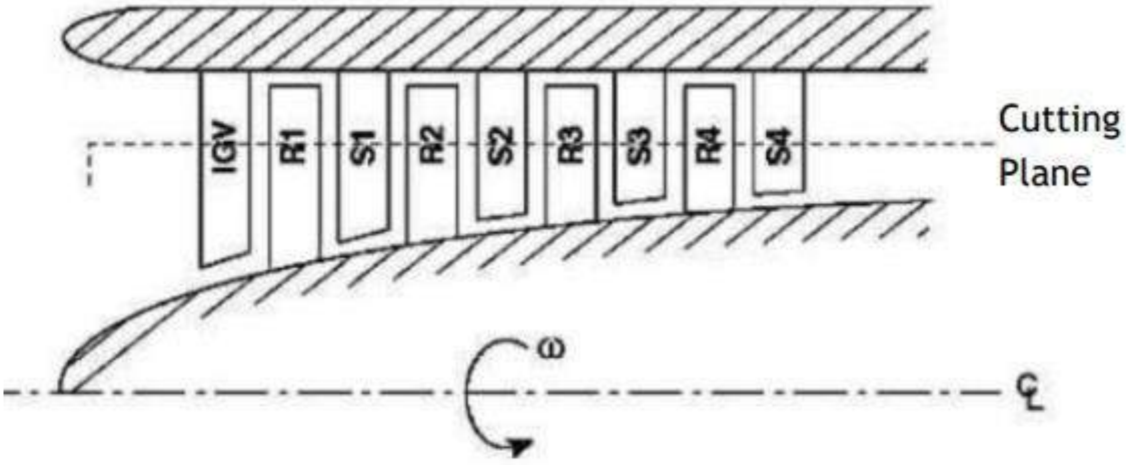


IGV

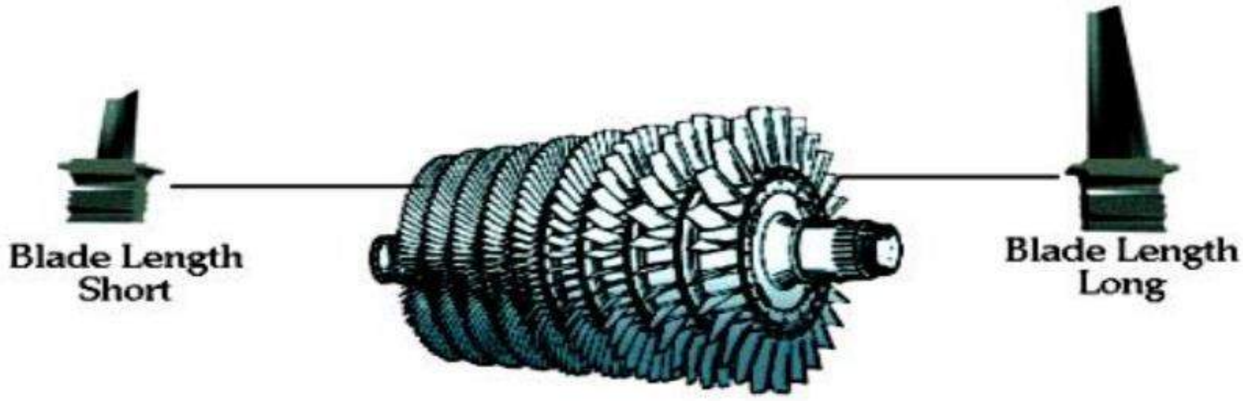
- *IGV permits fast, smooth acceleration of the turbine without compressor surge.*
- *A hydraulic cylinder mounted on a base cross member actuates the IGV through a large ring gear and multiple small pinion gears*
- Gear & Rack Material: Stainless steel

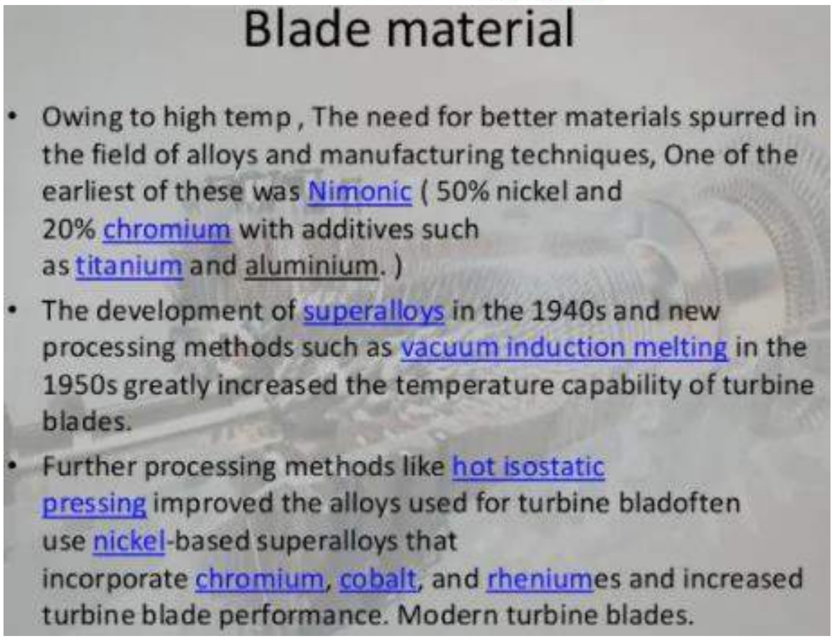
IGV Material: Cr-Ni-Cd ,C-450

**Axial-Flow Compressors**: A compressor consists of several stages. One rotor and one stator make-up a stage in a compressor. The axial flow compressor used in gas turbines typically has 17- 22 stages, with very high-pressure ratios (17:1 to 20:1 for industrial gas turbines, and 40:1 for aero engines).



Schematic representation of an axial flow compressor.





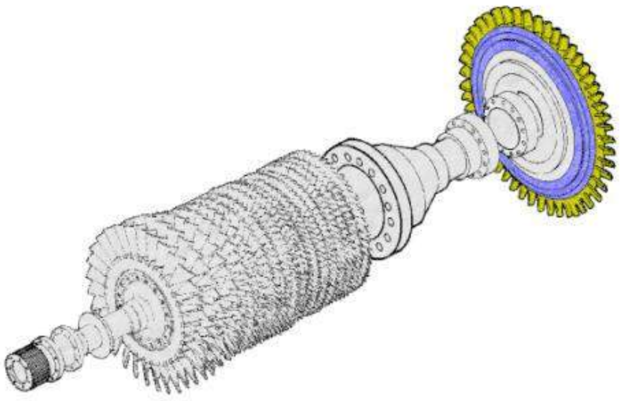
Blade material

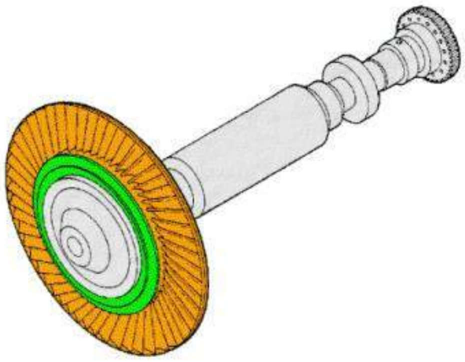
- Owing to high temp , The need for better materials spurred in the field of alloys and manufacturing techniques, One of the earliest of these was Nimonic ( 50% nickel and 20% chromium with additives such as titanium and aluminium. )
- The development of superalloys in the 1940s and new processing methods such as vacuum induction melting in the 1950s greatly increased the temperature capability of turbine blades.
- Further processing methods like hot isostatic pressing improved the alloys used for turbine bladoften use nickel-based superalloys that incorporate chromium, cobalt, and rheniumes and increased turbine blade performance. Modern turbine blades.

**Turbine Nozzle - Stator** ▪ The purpose of the turbine stator-nozzles is to: ▪ Change the direction of gas flow ▪ Increase gas velocity ▪ Reduce pressure and temperature of gases

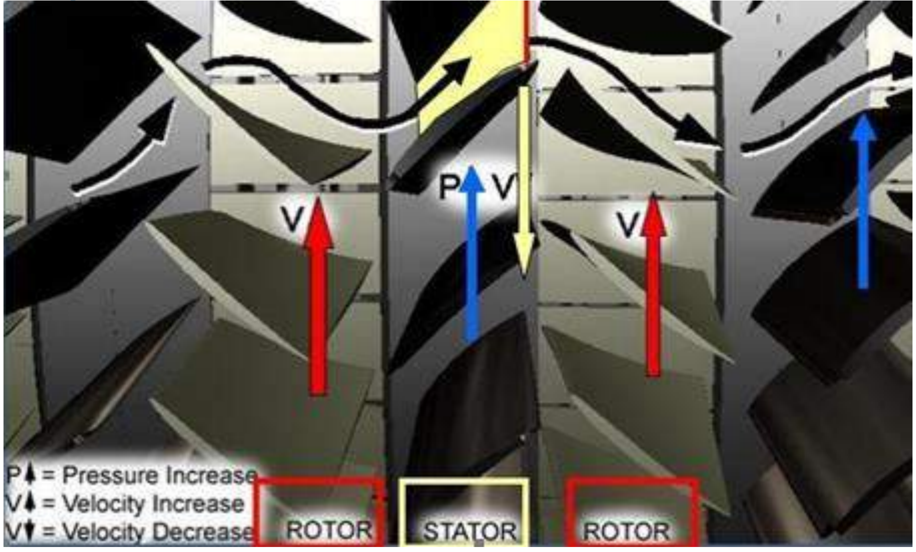
**Turbine Rotor**

The energy of the gases leaving the first row of turbine nozzle vanes encounters the next major component of the turbine section, the rotor or turbine wheel

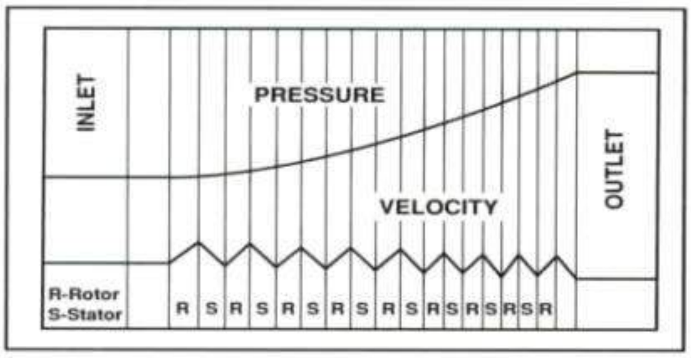


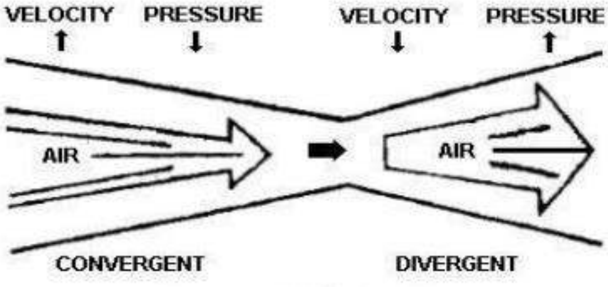


## Axial-Flow Compressors


V
P
V
V
P↑ = Pressure Increase
V↑ = Velocity Increase
V↓ = Velocity Decrease
ROTOR
STATOR
ROTOR

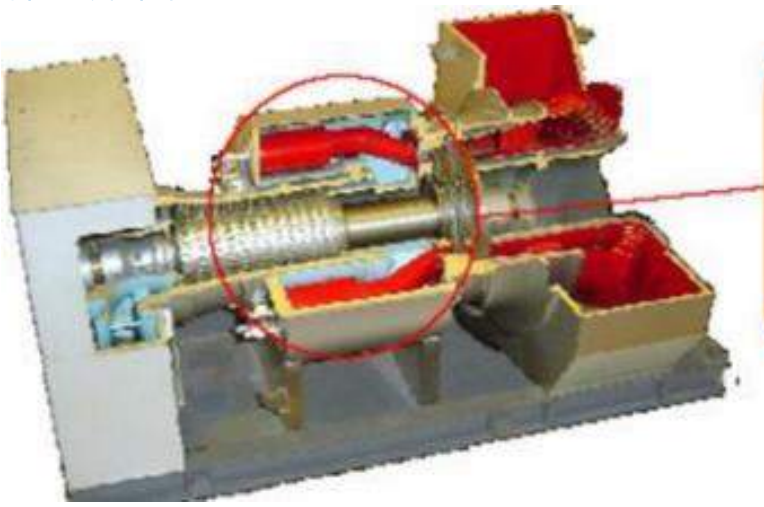
In an axial compressor air passes from one stage to the next, each stage raising the pressure slightly. By producing low-pressure increases on the order of 1.1:1 to 1.4:1, very high efficiencies can be obtained. The use of multiple stages permits overall pressure increases of up to 40:1.




VELOCITY ↑
PRESSURE ↓
VELOCITY ↓
PRESSURE ↑
AIR
AIR
CONVERGENT
DIVERGENT

Bernoulli's Principle

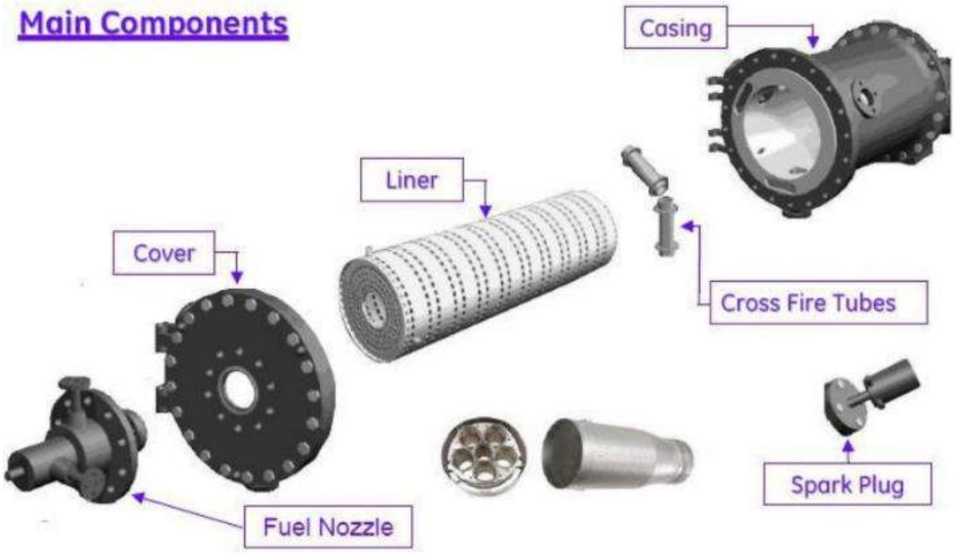
## Combustors

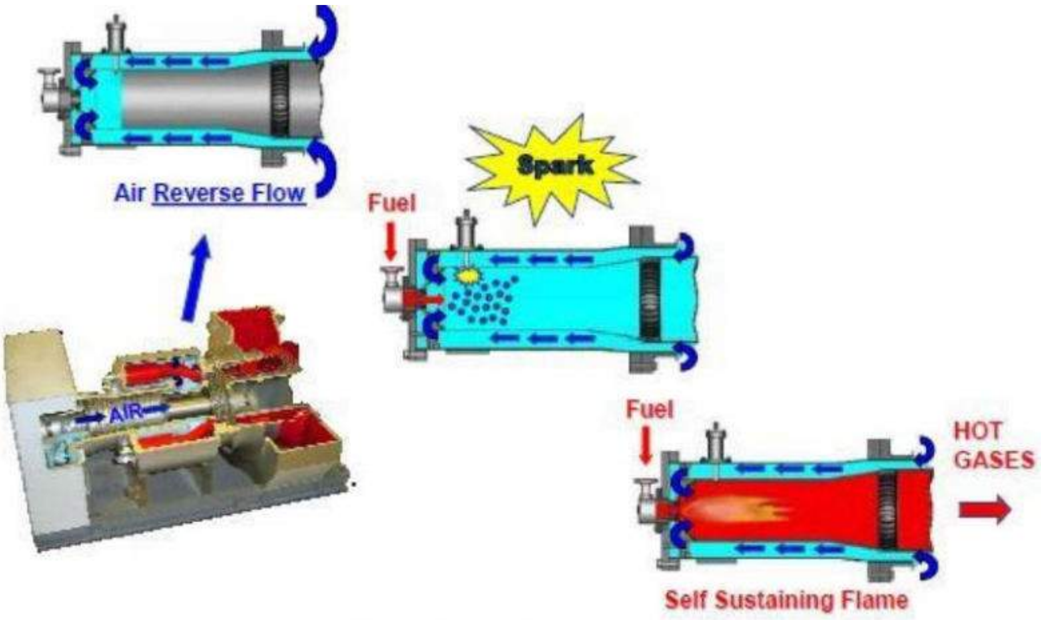


COMBUSTOR(s)

is the part of the engine where air is mixed with fuel and burned with a portion of the compressor air

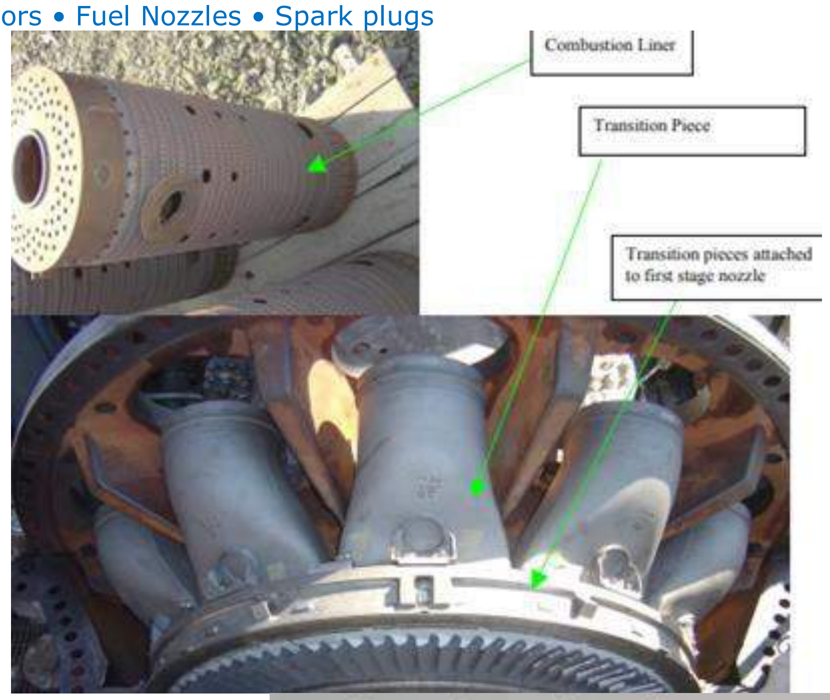
A combustor is a component or area of a gas turbine, where combustion takes place. It is also known as a burner, combustion chamber or flame holder. The combustor accepts air from the compressor and add heat energy to the flowing gases. This addition of heat causes the gases to expand and accelerate into the turbine section to power the turbine and the load.

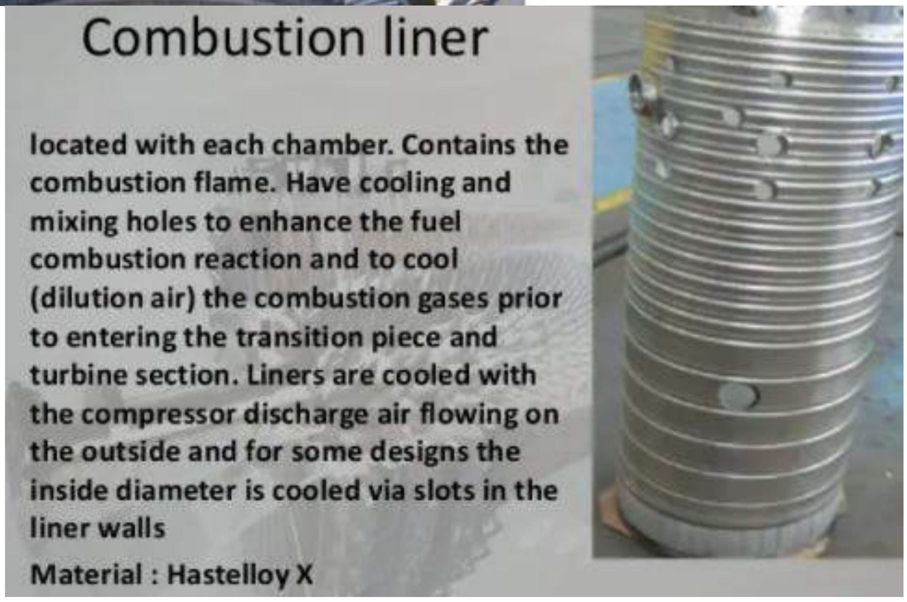

Main Components
Casing
Liner
Cover
Cross Fire Tubes
Spark Plug
Fuel Nozzle


Air Reverse Flow
Spark
Fuel
AIR
Fuel
HOT GASES
Self Sustaining Flame

**Combustion Sequence**

The combustion system is the reverse flow type which includes 14 combustion chambers having the components like: • Combustion Liners • Flow sleeves • Transition pieces • Cross fire Tubes • Flame detectors • Fuel Nozzles • Spark plugs

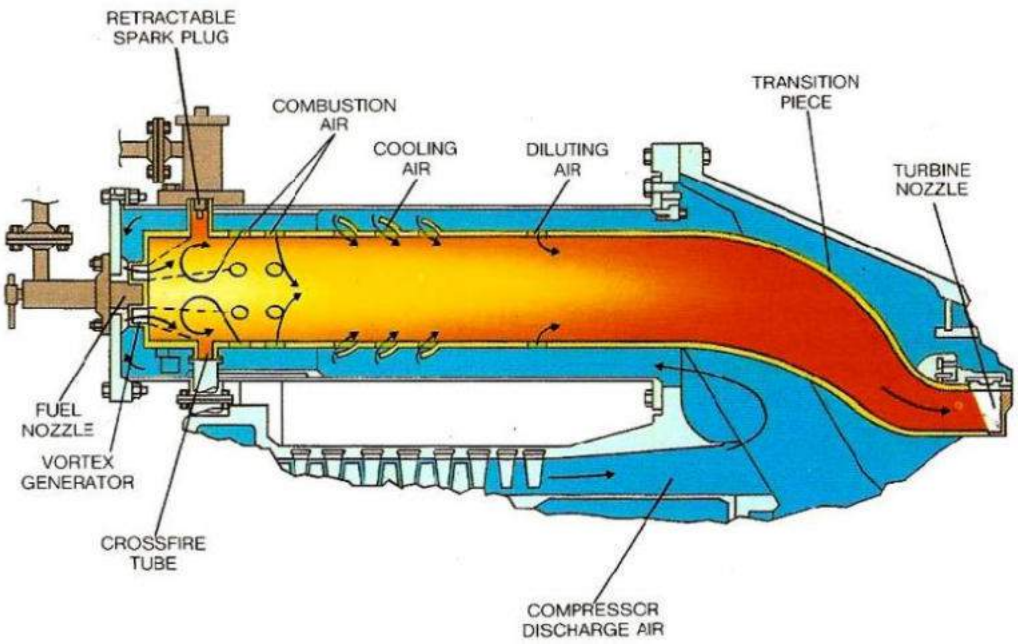

Combustion Liner
Transition Piece
Transition pieces attached to first stage nozzle



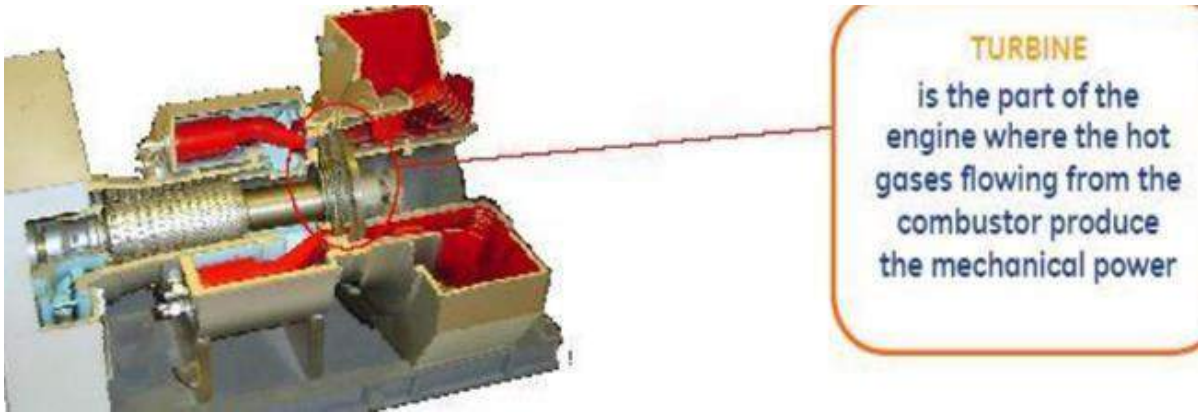
## Combustion liner

located with each chamber. Contains the combustion flame. Have cooling and mixing holes to enhance the fuel combustion reaction and to cool (dilution air) the combustion gases prior to entering the transition piece and turbine section. Liners are cooled with the compressor discharge air flowing on the outside and for some designs the inside diameter is cooled via slots in the liner walls

Material : Hastelloy X


RETRACTABLE SPARK PLUG
COMBUSTION AIR
COOLING AIR
DILUTING AIR
TRANSITION PIECE
TURBINE NOZZLE
FUEL NOZZLE
VORTEX GENERATOR
CROSSFIRE TUBE
COMPRESSOR DISCHARGE AIR

## Power Turbine



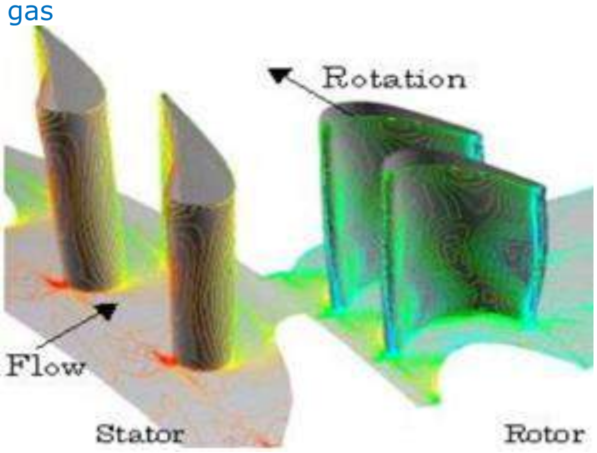
TURBINE is the part of the engine where the hot gases flowing from the combustor produce the mechanical power

The turbine section is where the high temperature gases from the combustion section are converted to shaft horsepower.

The turbine can consist of several stages. Each stage is comprised of stationary row of nozzles where the high energy gases are increased in velocity and directed toward a rotating row of buckets, or airfoils, attached to the turbine shaft. As the gas flows through the turbine rotating shaft, the gas kinetic energy is converted into horsepower

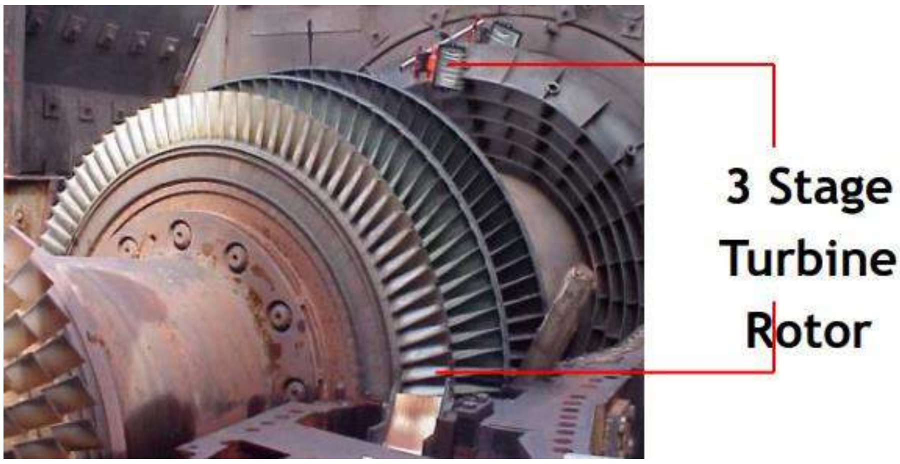
When the gas is expanded by the combustion Process, it forces its way into the discharge nozzles of the turbine where, because of their convergent shape, it is accelerated to about the speed of sound which, at the gas temperature, is about 2,500 feet per second. At the same time the gas flow is given a ’spin’ or ’whirl’ in the direction of rotation of the turbine blades by the nozzle guide vanes. On impact with the blades and during the subsequent reaction through the blades, energy is absorbed, causing the turbine to rotate at high speed and so provide the power for driving the turbine shaft and compressor

**Turbine Nozzle :** Change the direction of gas flow ▪ Increase gas velocity ▪ Reduce pressure and temperature of the gas


Rotation
Flow
Stator
Rotor

**Turbine Rotor** :The purpose of the turbine rotor is to extract mechanical energy to operate the compressor, accessories, and load. When the turbine wheel rotates it transfers energy to the shaft, which is connected to the compressor, the accessories, and/or the load.

As a rule, the total number of stages in a gas turbine is not more than 3—5.



**Gas Turbine Design Maintenance Features**: **The following features are designed to facilitate on-site maintenance:** All casings, shells and frames are split on machine horizontal centerline. Upper halves may be lifted individually for access to internal parts. With upper-half compressor casings removed, all stator vanes can be slide circumferentially out of the casings for inspection or replacement without rotor removal. With upper-half of the turbine shell lifted, each half of the first-stage nozzle assembly can be removed for inspection, repair or replacement without rotor removal. On some units, upper half, later-stage nozzle assemblies are lifted with the turbine shell, also allowing inspection and/or removal of the turbine buckets. All turbine buckets are moment weighed and computer charted in sets for rotor spool assembly so that they may be replaced without the need to remove or rebalance the rotor assembly. All bearing housings and liners are split on the horizontal centerline so that they may be inspected and replaced, when necessary. The lower half of the bearing liner can be removed without removing the rotor. All seals and shaft packings are separate from the main bearing housings and casing structures and may be readily removed and replaced. Fuel nozzles, combustion liners and flow sleeves can be removed for inspection, maintenance or replacement without lifting any casings or removing combustion cans. Inspection aid provisions have been built into gas turbines to facilitate conducting several special inspection procedures. These special procedures provide for the visual inspection and clearance measurement of some of the critical internal turbine gas-path components without removal of the gas turbine outer casings and shells. These procedures include gas path bore scope inspection and turbine nozzle axial clearance measurement

**Bore scope Inspections** : gas turbines incorporate provisions in both compressor casings and turbine shells for gas path visual inspection of intermediate compressor rotor stages, first, second and third stage turbine buckets and partly the turbine nozzle partitions by means of the optical bore scope. These provisions, consisting of radially aligned holes through the compressor casings, turbine shell and internal stationary turbine shrouds, are designed to allow the penetration of an optical bore scope into the compressor or turbine flow-path area. An effective bore scope inspection program can result in removing casings and shells from a turbine unit only when it is necessary to repair or replace parts. recommend to perform a planned bore scope inspection together with a combustion inspection. It should be recognized that these bore scope inspection intervals are based on average unit operating modes. Adjustment of these bore scope intervals may be made based on operating experience and the individual unit mode of operation, the fuels used and the result of previous bore scope inspections. The application of a monitoring program utilizing a bore scope will allow scheduling outages and pre-planning of parts requirements, resulting in lower maintenance costs and higher availability and reliability of the gas turbine

**Major Factors Influencing Maintenance and Equipment:** There are many factors that can influence equipment life and these must be understood and accounted for in the owner's maintenance planning. Starting cycle, power setting, fuel and level of steam or water injection are key factors in determining the maintenance interval requirements as these factors directly influence the life of critical gas turbine parts. Fuel - Firing Temperature - Steam / Water Injection - Cyclic Effects In the approach of turbine to maintenance planning, a gas fuel, base load application, with no water or steam injection, is established as the baseline condition, which sets the maximum recommended maintenance intervals. For operation that differs from the baseline, maintenance factors are established that determine the increased level of maintenance that is required.

**Potential failure modes** - hot gas path components Continuous Duty ,Cyclic Duty - Rupture - Thermal Mechanical Fatigue - Creep Deflection - High-Cycle Fatigue - Rubs / Wear - Corrosion - Foreign Object Damage - Oxidation – Erosion.

## Operating inspection data parameters

- SPEED
- LOAD
- FIRED STARTS
- FIRED HOURS
- SITE BAROMETRIC READING
- TEMPERATURES
  - INLET AMBIENT
- COMPRESSOR DISCHARGE
  - TURBINE EXHAUST
  - TURBINE WHEELSPACE
  - LUBE OIL HEADER
  - LUBE OIL TANK
  - BEARING DRAINS
  - EXHAUST SPREAD
- PRESSURES
  - COMPRESSOR DISCHARGE
  - LUBE PUMP(S)
  - BEARING HEADER
  - COOLING WATER
  - FUEL
  - FILTERS (FUEL, LUBE, INLET AIR)
- GENERATOR
  - OUTPUT VOLTAGE
  - PHASE CURRENT
  - VARS
  - LOAD
  - FIELD VOLTAGE
  - FIELD CURRENT
  - STATOR TEMP.
  - VIBRATION
- VIBRATION DATA FOR POWER TRAIN
- START UP TIME
- COAST-DOWN TIME

## Combustion inspection - key elements

| Key Hardware | Inspect for | Inspection / Actions: |
|---|---|---|
| Combustion Liners | ▪ Foreign Objects | Repair / Refurbishment |
| Combustion Covers | ▪ Abnormal Wear | ▪ Liners |
| Fuel Nozzles | ▪ Cracking | Cracking / Erosion / Wear |
| Transition Pieces | ▪ Liner Cooling Hole Plugging | TBC Repair |
| Cross fire Tubes | ▪ TBC Coating Cond. | ▪ Transition Pieces |
| Flow Sleeves | ▪ Oxidation/Corrosion/Erosion | Wear |
| Purge Valves | ▪ Hot Spots / Burning | TBC Repair |
| Check Valves | ▪ Missing Hardware | Distortion |
| Flame Detectors | ▪ Clearance Limits | ▪ Fuel Nozzles |
| Spark Plugs | ▪ Bore scope Compressor and | Plugging |
| Flex Hoses | Turbine | Wear / Erosion |
| | ▪ Tightness | Flow Test |
| | | ▪ Cross Fire Tubes |
| | | Wear / Burning |
| | | ▪ Pressure Test (Flex Hoses) |

## Hot gas path inspection - key elements

| Key Hardware | Inspect for | Inspection / Actions: |
|---|---|---|
| Nozzles (1, 2, 3) | ▪ Foreign Object Damage | Repair/Refurbishment/Replace |
| | ▪ Oxidation / Corrosion / | ▪ Nozzles |
| | Erosion | Weld Repair |
| Buckets (1, 2, 3) | ▪ Cracking | Reposition |
| | ▪ Cooling Hole Plugging | Recoat |
| | ▪ Remaining Coating Life | ▪ Buckets |
| Stator Shrouds | ▪ Nozzle Deflection / | Strip & Recoat |
| | Deterioration | Weld Repair |
| | ▪ Abnormal Deflection / | Creep Life Limit |
| | Deterioration | Top Shroud Deflection |
| IGV's & Bushings | ▪ Abnormal Wear | |
| | ▪ Missing Hardware | |
| Compressor Blading | ▪ Clearance Limits | |
| (Bore scope) | | |

## Gas turbine major inspection - key elements

Key Hardware

Compressor Blading
Turbine Wheels
Fir Tree Guide
Journal and Seal Surfaces
Bearing, Seals
Inlet Systems
Exhaust Systems

Inspect for

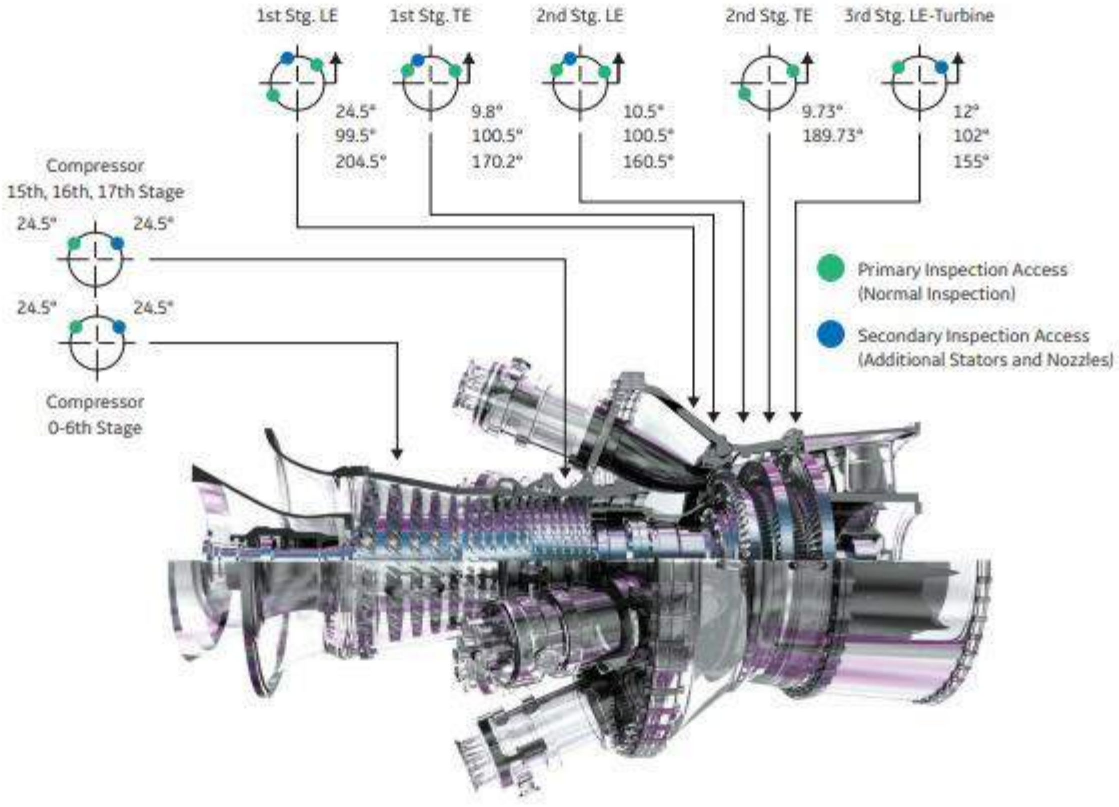
- Foreign Object Damage
- Oxidation / Corrosion / Erosion
- Cracking
- Leaks
- Abnormal Wear
- Missing Hardware
- Clearance Limits

Inspection / Actions:

Repair / Refurbishment / Replace

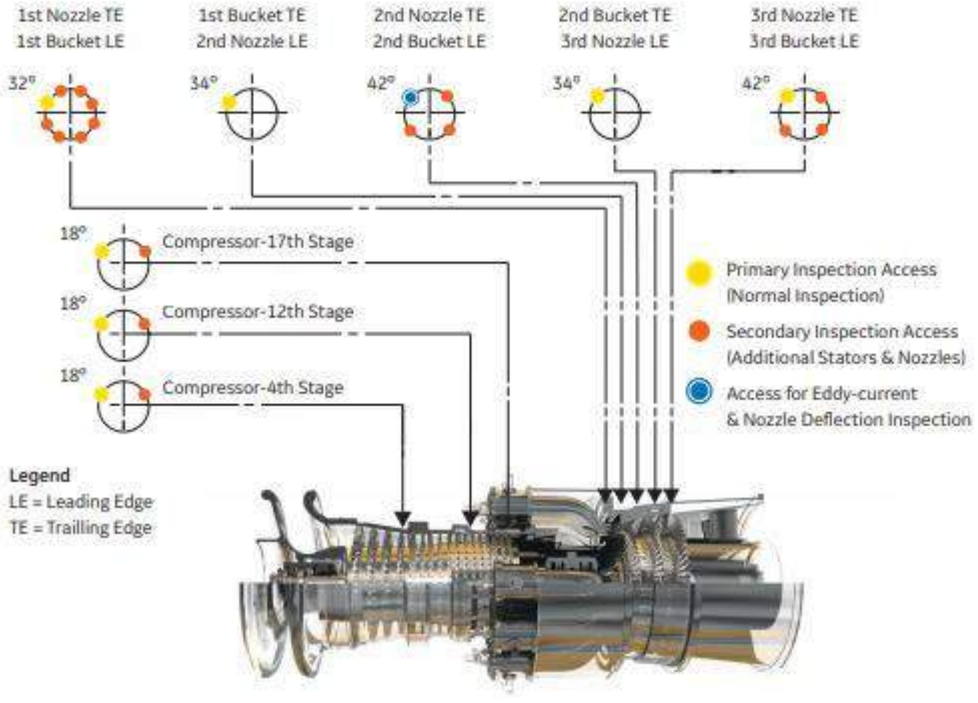
- Stator Shrouds
  Cracking/Oxidation/Erosion
- Buckets
  Coating Deterioration
  Rubs/Cracking
  Tip Shroud Deflection
  Creep Life Limit
- Nozzles
  Deterioration
- IGV-Bushings Wear
- Bearings/Seals
- Compressor Blades

## Boroscope inspection ports (example)


1st Stg. LE
24.5°
99.5°
204.5°
1st Stg. TE
9.8°
100.5°
170.2°
2nd Stg. LE
10.5°
100.5°
160.5°
2nd Stg. TE
9.73°
189.73°
3rd Stg. LE-Turbine
12°
102°
155°
Compressor
15th, 16th, 17th Stage
24.5°
24.5°
24.5°
24.5°
Compressor
0-6th Stage

● Primary Inspection Access (Normal Inspection)

● Secondary Inspection Access (Additional Stators and Nozzles)


1st Nozzle TE
1st Bucket LE
32°
1st Bucket TE
2nd Nozzle LE
34°
2nd Nozzle TE
2nd Bucket LE
42°
2nd Bucket TE
3rd Nozzle LE
34°
3rd Nozzle TE
3rd Bucket LE
42°
18°
Compressor-17th Stage
18°
Compressor-12th Stage
18°
Compressor-4th Stage

● Primary Inspection Access (Normal Inspection)

● Secondary Inspection Access (Additional Stators & Nozzles)

◉ Access for Eddy-current & Nozzle Deflection Inspection

Legend
LE = Leading Edge
TE = Trailling Edge

**Methods of compressor cleaning**: A loss of gas turbine performance is indicated by a decrease of power output and an increase in heat rate. Often a loss of performance is a direct result of fouling of the axial flow compressor. Fouled compressors result in reduced air flow, lower compressor efficiency, and a lower compressor pressure ratio.

If any deposits, including dust or filmy deposits, can be wiped or scraped off these areas, the compressor is fouled sufficiently to affect performance. The initial inspection also reveals whether the deposits are oily or dry. For oily deposits, a water-detergent wash is required. Location of the source of the oil and correction should be accomplished before cleaning to prevent recurrence of the fouling. If only dry deposits are found, water alone may be sufficient.

**Performance Monitoring**: A second method for detecting a fouled compressor is performance monitoring. Performance monitoring involves obtaining gas turbine data on a routine basis which in turn is compared to baseline data to monitor trends in the performance of the gas turbine. The performance data is obtained by running the unit at steady-stage BASE load and recording output, exhaust temperature inlet air temperature, barometric pressure, compressor discharge pressure and temperature, and fuel consumption. The data should be taken carefully with the unit warmed up. Output and heat rate can be corrected to a standard condition using the turbine performance curves and an analysis can be made of compressor pressure ratio and efficiency. The current performance levels can be compared to baseline data and will aid in determining the problem area. If performance analysis indicates compressor fouling, it should be verified by a visual inspection.

**Cleaning Methods** There are three methods used for compressor cleaning, off-line, on-line and solid compound cleaning. There are two types of cleaning agents: solid compounds and liquids.

**Liquid Compound Cleaning**: Liquid cleaning involves washing the compressor with water and/or detergents. This can be accomplished while the turbine is on-line or off-line. As the on-line washing practice has been found to be most effective when carried out daily, the specification on the liquid must be more restrictive for on-line washing than off-line washing. The water specifications for off-line and on-line cleaning are given in OEM. Except for the pH, the restrictions in these specifications are concerned with deposits and corrosion of the hot gas path. The pH restriction is concerned with corrosion in the water handling system. High purity demineralized water after contact with air will have a pH in the range of 5.0 to 6.0. Thus, allowance has been made in the pH provided this is the reason for the low pH. If a detergent is used, additional restrictions are required to insure no harm will result to turbine components. In general, deposits will contain some water-soluble material and oils. The latter will be more amenable to removal by detergent; but the deposit may be removable by water washing alone, depending on the amount of water-soluble material present. Hot water at 65-93°C is generally more effective than cold water. There are a number of detergents available for this purpose, some of which, along with the deposits that have been removed, may constitute a hazardous solid waste when used for an off-line wash. Because of this possibility, local regulations should be considered for the storage, handling and treatment of the water wash effluent when the drain and containment system is designed.

**Solid Compound Cleaning**: There are two types of solid compounds used: Organic - nutshells and rice and Inert - catalyst supports, spent catalysts and polishing powders. Combustible compounds are preferred to inert compounds. The organics will burn up in the combustion process while the inerts will not and may cause erosion or blocked cooling holes

Recent experience in the use of rice for compressor cleaning suggests that solid compound cleaning can be detrimental to compressor blade coatings and to compressor blade surface finish. Shallow impact craters of several mils in diameter and tenths of mils in depth have been found on clean rotor blading upon inspection immediately after solid compound cleaning. Furthermore, an increase of surface roughness has been observed on this blading.

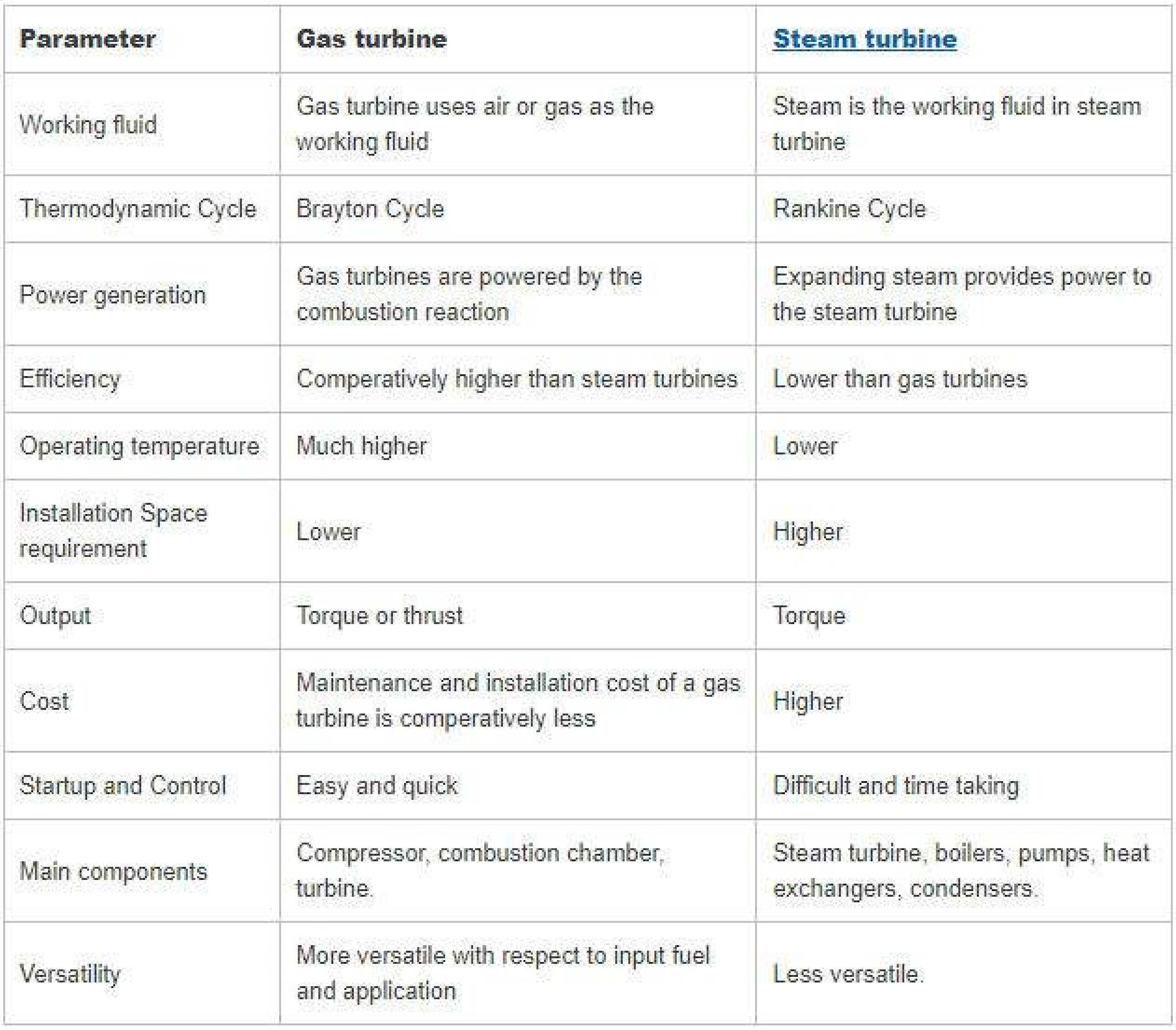
**Field performance testing procedures:** Purpose of test shall be the measurement of turbine or generator output and fuel heat consumption at one more load condition.

Sufficient supporting data shall be recorded to enable the "as tested" performance to be corrected to the standard conditions so that an accurate comparison may be made between tested and base-line machine capability and heat rate at specified conditions. The attached data sheets should be used to record the test data.

During unit disassembly many parts will require cleaning. The most generally accepted methods used for cleaning Gas Turbine parts are solvents, steam and abrasive blasting

Hand cleaning methods Wire brushes, emery cloth, carborundum stones, steel wool and similar devices are all acceptable for cleaning when used properly. Do not use a flat stone on a round journal. Clean all bolt threads of old anti-seize and other contaminants. Use a hand wire brush (not a power wire wheel) and solvent. Keep parts separated when cleaning. Bolts should be reinstalled in the same flange from which they were removed

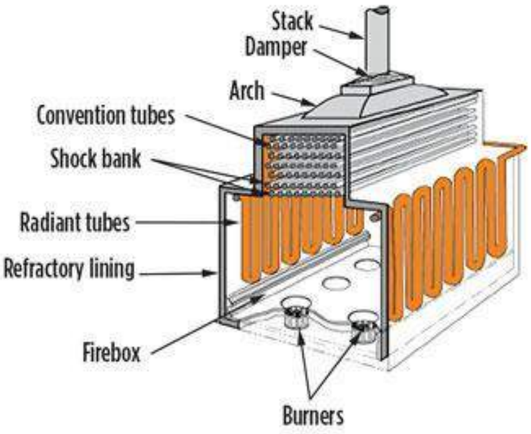
## Gas turbine vs steam turbine

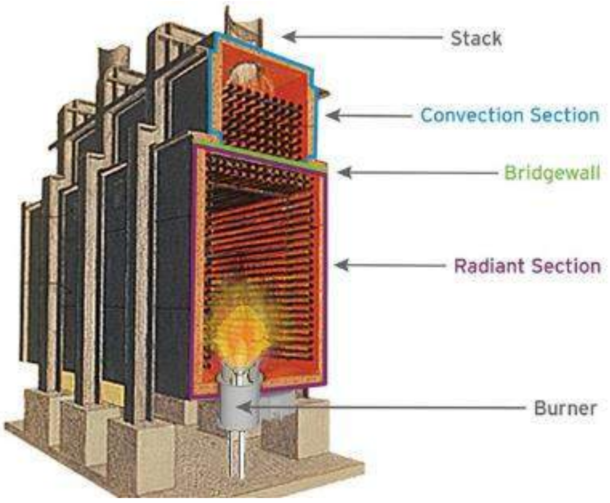


| **Parameter** | **Gas turbine** | **Steam turbine** |
|---|---|---|
| Working fluid | Gas turbine uses air or gas as the working fluid | Steam is the working fluid in steam turbine |
| Thermodynamic Cycle | Brayton Cycle | Rankine Cycle |
| Power generation | Gas turbines are powered by the combustion reaction | Expanding steam provides power to the steam turbine |
| Efficiency | Comperatively higher than steam turbines | Lower than gas turbines |
| Operating temperature | Much higher | Lower |
| Installation Space requirement | Lower | Higher |
| Output | Torque or thrust | Torque |
| Cost | Maintenance and installation cost of a gas turbine is comperatively less | Higher |
| Startup and Control | Easy and quick | Difficult and time taking |
| Main components | Compressor, combustion chamber, turbine. | Steam turbine, boilers, pumps, heat exchangers, condensers. |
| Versatility | More versatile with respect to input fuel and application | Less versatile. |

## BOILER / FURNACE –maintenance

### Refinery Furnace:





Furnace / Boiler consist of three major components: the steel structure, the refractory, and the tubes and pipes that carry the fluid. The steel structure is durable and can generally remain in service for 30 yr–40 yr without any major maintenance (e.g., painting or some other relatively minor repair that does not call for major cost, or that is normally less than 1% of the total heater cost). Refractory repair and replacement in heaters is part of regular maintenance checks, and generally repairs are required between turnarounds every 3 yr–4 yr. The lifetime of heater tubes varies from 5 yr–15 yr, depending on the material of construction and the severity of conditions they are subjected to during heater operation.

Heaters are used to provide requisite heat to the fluid in an enclosed box (box or cylindrical). They are internally lined with refractory using single and multiple burners where fuel is fired for generating heat. The fluid flows inside the tubes and pipes and picks up heat from the hot flue gases generated from burners, mainly through radiation and/or convection.

**ISOLATION**

- ✓ Isolation: De-pressurize pipelines and Isolate all valves of those pipelines connected with Boiler / furnace .
- ✓ Install the spades on upstream to blind the lines.

**DE-GASSING**

- ✓ Open the man ways, keep it open 24 hours for natural degassing.
- ✓ After 24 hours start degassing with air ejectors.
- ✓ Check temp. inside boiler , take clearance from operation & HSE for entering inside .
- ✓ Once LEL become 0% then obtain confined space entry permit to enter inside for inspection, cleaning , and for repair .
- ✓ Check VOC with the VOC gas monitor, if VOC is less than 15% can work without full face mask. But more than this level cleaning should be carried out with full face mask (organic cartridge).
- ✓ Arrange proper lightning , blower , educator , compressor , fan ..etc..

**Inside cleaning**

- ✓ Cleaning team inside should have multi-gas detector for monitoring the LEL during cleaning.
- ✓ Clening of tubes , floor , firing burner / manifold

**INSPECTION & REPLACEMENT**

**BOTTOM FLOOR**

- ✓Inspect floor , refractory , tube , support , burner assembly ..etc
- ✓Remove all loosen or fallen or damage part .

**TUBES**

- ✓Inspect tubes – sagging , bowing , oxidation / scaling , bulging , metallurgical change, effect of expansion , corrosion , thermal fatigue , support
- ✓Check tube thickness – UT , metallurgical test (if require) , radiography (if require) , hammer testing
- ✓Check for tube cleaning ( through circulate gas oil , steam / air method , chemical cleaning , through hydro HP machine ( check chlorine content of water should be less than 50 ppm)
- ✓Hydro test of tube
- ✓Internal Tube cleaning (decoking)

**External surface interactions (flue gas interactions) include:**

- Fuel-fired
- External corrosion, oxidation, scaling, sulfidation (due to flue gas, high temperature, presence of excess or insufficient oxygen, etc.)

- Other metallurgical interactions, such as carburization, decarburization, spheroidization and grain growth
- Flame impingement, hot spots
- Burner firing.

**Internal surface interactions (feed interactions) include:**

- Type of feed (process fluid inside the tube)
- Internal corrosion and erosion (fluid composition, temperature, velocity, tube MOC)
- Sulfidic corrosion, naphthenic acid corrosion
- Coking
- Decoking/pigging.

**Piping , pipe joints**

- Check visual inspection for leak , looseness , support , weld joints ..etc. & repair accordingly

**Refractory job**

- Check visual inspection for crack erosion , excessive fluxing (melting of refractory), bulging , fallout, looseness , joints ..etc. & repair accordingly
- Check insulation

**Burner assembly job**

- Check spares of burner – gas tip , oil tip , nozzle pipe ..etc..
- Check visual inspection for overheating , crack , looseness , joints ..etc. & repair accordingly

**Auxiliary equipment's** – Fuel pump , strainer , blower / fan , Duct , water system , soot blower , dampers..etc.

**Testing of boilers / Furnace** – hydro test

- **Air Preheater** - Heat exchanger device that uses some of the heat in the flue gases to raise the temperature of the air supply to the burners.
- **Breeching** - The hood that collects the flue gas at the convection section exit.
- **Center Wall** - A refractory wall in the radiant section, which divides it into two separate cells.
- **Coil** - A series of straight tube lengths connected by 180o return bends, forming a continuous path through which the process fluid passes and is heated.
- **Convection Section** - The portion of a heater, consisting of a bank of tubes, which receives heat from the hot flue gases, mainly by convection.
- **Corbelling** - Narrow ledges extending from the convection section side walls to prevent flue gas from flowing preferentially up the side of the convection section, between the wall and the nearest tubes.
- **Crossover** - Piping which transfers the process fluid either externally or internally from one section of the heater to another.
- **Damper** - A device to regulate flow of gas through a stack or duct and to control draft in a heater.
- **Draft** - The negative pressure (vacuum) at a given point inside the heater, usually expressed in inches of water.
- **Excess Air** - The percentage of air in the heater in excess of the stoichiometric amount required for combustion.
- **Extended Surface** - Surface added to the outside of bare tubes in the convection section to provide more heat transfer area.
- **Film** - A thin fluid layer adjacent to a pipe wall that remains in laminar flow, even when the bulk flow is turbulent.
- **Fire Box -** A term used to describe the structure which surrounds the radiant coils and into which the burners protrude.
- **Flue Gas** - A mixture of gaseous products resulting from combustion of the fuel.
- **Fouling -** The building up of a film of dirt, ash, soot or coke on heat transfer surfaces, resulting in increased resistance to heat flow.
- **Forced Draft** - Use of a fan to supply combustion air to the burners and to overcome the pressure drop through the burners.
- **Header Box** - The compartment at the end of the convection section where the headers are located.
- **Induced Draft** - Use of a fan to provide the additional draft required over that supplied by the stack, to draw the flue gas through the convection section, and any downstream heat recovery equipment.
- **Natural Draft** - System in which the draft required to move combustion air into the heater and flue gas through the heater and out the stack is provided by stack effect alone.
- **One-Side Fired Tubes** - Radiant section tubes located adjacent to a heater wall have only one side directly exposed to a burner flame. Radiation to the back side of the tubes is by reflection/ re-radiation from the refractory wall.
- **Pass** - A coil that transports the process fluid from fired heater inlet to outlet.

- **Radiant Section** - The section of the fired heater in which heat is transferred to the heater tubes primarily by radiation from high-temperature flue gas.
- **Shield Section** - The first two tube rows of the convection section
- **Sootblower -** A steam lance (usually movable) in the convection section for blowing soot and ash from the tubes using high-pressure steam.
- **Stack -** A cylindrical steel, concrete or brick shell which carries flue gas to the atmosphere and provides necessary draft.
- **Stack Effect** - The difference between the weight of a column of high-temperature gases inside the heater and/or stack and the weight of an equivalent column of external air, usually expressed in inches of water per foot of height.
- **Stack Temperature -** The temperature of the flue gas as it leaves the convection section, or air preheater directly upstream of the stack.
- **Two-Side Fired Tubes** - Radiant section tubes which are exposed on both sides to direct radiation from the burners.

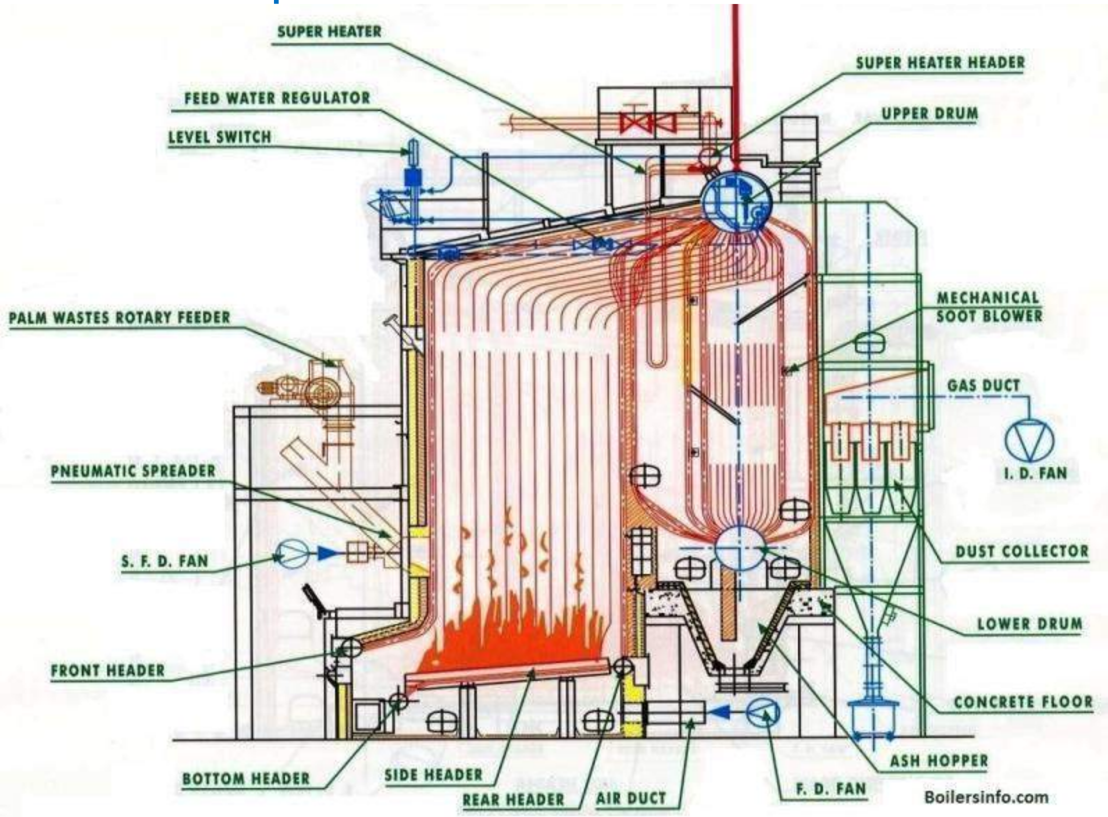
**Reference:** API 573 / API 530-560

## Boiler:

### What is a water tube boiler?

Water tube boilers were developed for a variety of reasons, including the need for higher steam pressures, higher steam generation rate, superheated steam. These types of boilers have quicker response to load changes.

### Water tube boiler parts and functions.


SUPER HEATER
SUPER HEATER HEADER
FEED WATER REGULATOR
UPPER DRUM
LEVEL SWITCH
MECHANICAL SOOT BLOWER
PALM WASTES ROTARY FEEDER
GAS DUCT
I. D. FAN
PNEUMATIC SPREADER
DUST COLLECTOR
S. F. D. FAN
LOWER DRUM
FRONT HEADER
CONCRETE FLOOR
ASH HOPPER
BOTTOM HEADER
SIDE HEADER
REAR HEADER
AIR DUCT
F. D. FAN
Boilersinfo.com

### water tube boiler

In the water tube boiler, the water and steam flow inside the tubes and the hot gases flow over the outside surfaces. Where as in fire tube boilers hot gases from combustion travels through the tubes. flue gases produced from furnace/boiler where fuel is burnt.

### Water tube boiler design and working

In a typical Water tube boiler design as shown in the figure, it consists of two drums the steam drum and the water or mud drum. On this design straight tubes were rolled into mud drum, and the front headers were connected to the steam drum. The rear header was connected to a horizontal box header, which was also attached to the steam drum. The tubes were inclined to promote water circulation. There was also a spring loaded safety valve on top of the steam drum. In a water tube boiler fuel is fired into a water cooled furnace. Sheet metal and refractory enclosing the boiler called casing. At the end of the furnace, the flue gas turns into the convection section and travels towards the stack.

All boilers have a radiant and a conviction sections, tubes around the furnace are called generation or riser tubes about a half of steam is generated in this area rest of the steam is produced in the convection section. Water inside the tubes become hot and due to natural circulation steam is collected and separated in the steam drum. Pre heated (economizer) Feed water is continually feed in the steam drum with feed water pump.

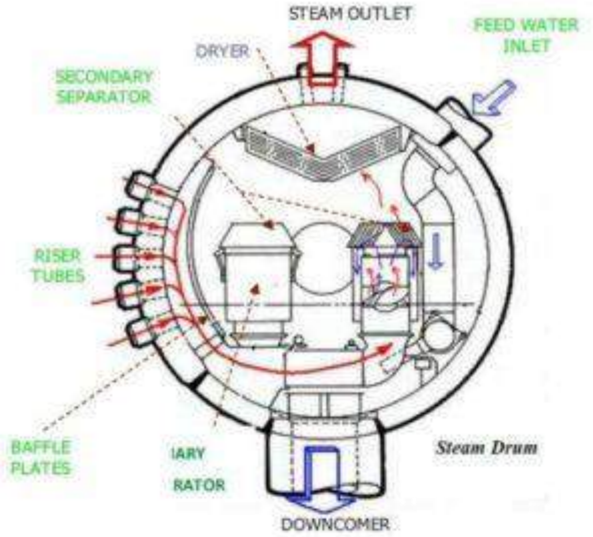
These boilers were common in the Industries which had big demands for electrical power and steam. Steam generated at high pressure and superheated would be fed to a turbine driving an alternator to generate electricity. Low-pressure steam leaving the turbine would then be used for the process.

### Water tube boiler parts and their functions

There are many pressure parts and non-pressure parts in a water tube boiler we only discuss main water tube boiler parts and function.

### Steam drum

Steam drum is a collection vessel for steam & water. Here water & steam is separated. It has steam separators. Steam goes from top side to super heater & water goes from the bottom through down comer Mud drum, then to furnace bottom ring headers (bottom of furnace water wall).



**Steam drum of water tube boiler**

It has two types of draining arrangement (a) CBD- continuous blow down used when Si02 or TDS is on the higher side. (b) Emergency blow down is used when drum level is high high. Boiler mountings and accessories like the safety valve, water level gauge and pressure gauge, feed water inlet connection are installed on this drum. Drum internals includes cyclone separators baffle plates rose pipe and the dry pipe. The main function of the steam drum is to provide water storage and space to separate steam from water.

### Mud or Water Drum

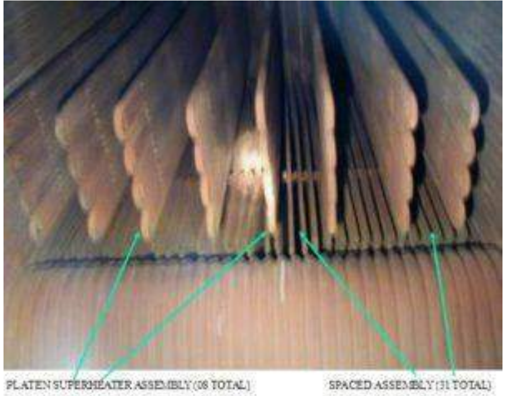
Mud or water drum the lower drum is directly attached to upper steam drum with large no of straight tubes bundles called boiler bank tubes. Solids and mud can settle in this mud drum for removal through periodic blowdown. Some times desuperheater coil also installed in this drum to recover heat from superheated steam. Draining arrangement of this drum is through one or two boiler blowdown connections to control TDS or to fully drain the boiler when out of service.

### Water walls

Tubing arrangement around the Boiler to extract heat from fuel to generate steam is called water wall circuit. These water walls can be arranged in line arrangement or stagger arrangement. Water walls get the heat from radiation and approximately absorb the 50% of the total heat produced in the furnace.

### Super heater

If the temperature of the steam is above its saturation temperature then it is called superheated steam. The super heater (heat exchanger) is used to increase the temperature of the steam. These are bundles of high strength tube which can bear temperature 600C Depending upon the material of tubes Mostly SA-213 is used. In most industrial water tube boilers the superheater is placed where flue gases make their turn from the radiant to the convection section of the boiler. There are three types of super heaters convection, radiant and conv-radient super heaters.


PLATEN SUPERHEATER ASSEMBLY (08 TOTAL)
SPACED ASSEMBLY (31 TOTAL)

### Economizer

Economizer (heat exchanger) is the boiler accessory used to recover the heat of flue gas that leaving the boiler by heating feed water. The efficiency of a boiler can be increased with an economizer. 60C rise in feed water temperature with the help of economizer can save up to 1% of fuel. Typically economiser is used before the air heater in flue gas path of the boiler to increase the boiler efficiency.

**Air Heater**

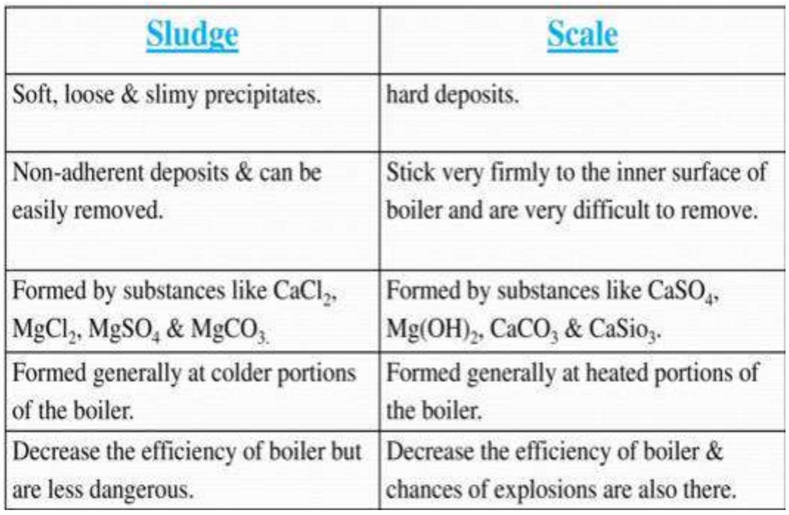
Air supplied to a boiler for combustion is pre heated with the help of air heater by recovering the heat of waste flue gas that leaves the economizer. 20C rise in temperature of combustion air can save up to 1% of total fuel.

Air heaters are classified into two main types recuperative Air heaters and regenerative Air heaters.

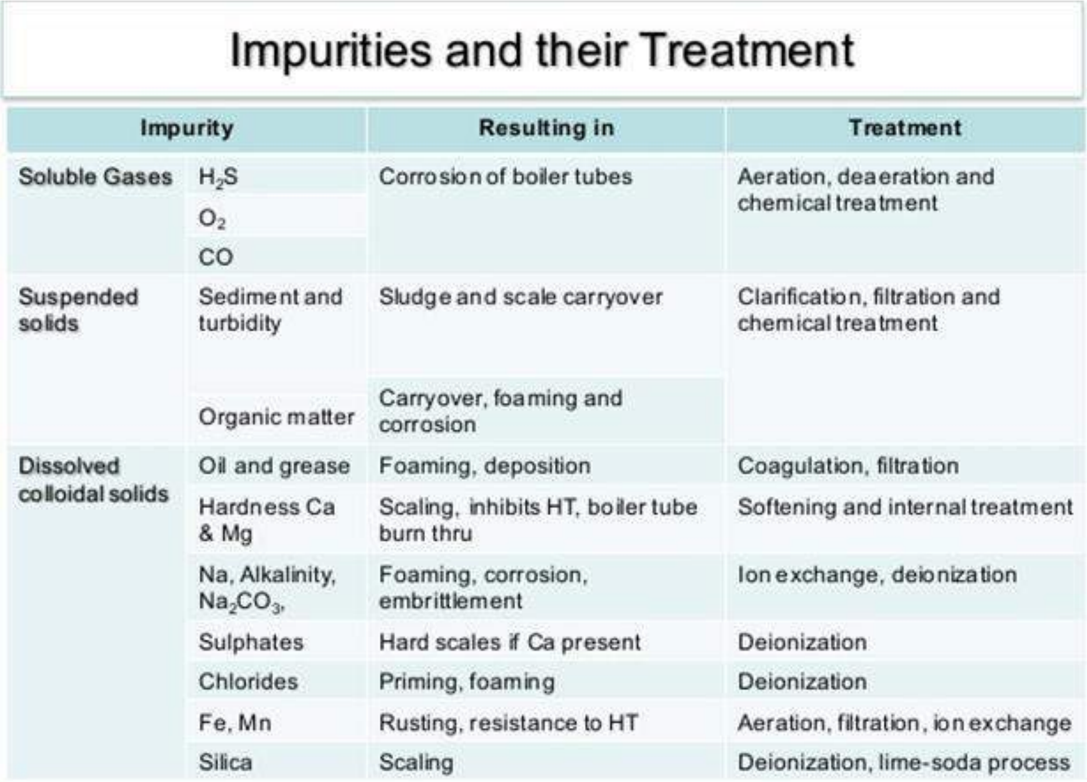
**Boiler Fans**

For combustion of fuel in the boiler furnace air is drawn from the atmosphere and pushed through the ducts with forced draught fan to furnace where air reacts with fuel and become flue gas, the flue gas is then extracted from the furnace with the help of Induced draught fan. The fan used in large water tube boilers are FD fans, ID fans, Primary air fans, Secondary air fans and Gas recirculation fans.

Other main water tube boiler parts are burning equipment burners and furnace and gas cleaning devices like ESP Cyclone Separators and bag filters.



| Sludge | Scale |
|---|---|
| Soft, loose & slimy precipitates. | hard deposits. |
| Non-adherent deposits & can be easily removed. | Stick very firmly to the inner surface of boiler and are very difficult to remove. |
| Formed by substances like $CaCl_2$, $MgCl_2$, $MgSO_4$ & $MgCO_3$. | Formed by substances like $CaSO_4$, $Mg(OH)_2$, $CaCO_3$ & $CaSio_3$. |
| Formed generally at colder portions of the boiler. | Formed generally at heated portions of the boiler. |
| Decrease the efficiency of boiler but are less dangerous. | Decrease the efficiency of boiler & chances of explosions are also there. |



### Impurities and their Treatment

| Impurity | | Resulting in | Treatment |
|---|---|---|---|
| Soluble Gases | $H_2S$ | Corrosion of boiler tubes | Aeration, deaeration and chemical treatment |
| | $O_2$ | | |
| | CO | | |
| Suspended solids | Sediment and turbidity | Sludge and scale carryover | Clarification, filtration and chemical treatment |
| | Organic matter | Carryover, foaming and corrosion | |
| Dissolved colloidal solids | Oil and grease | Foaming, deposition | Coagulation, filtration |
| | Hardness Ca & Mg | Scaling, inhibits HT, boiler tube burn thru | Softening and internal treatment |
| | Na, Alkalinity, $Na_2CO_3$, | Foaming, corrosion, embrittlement | Ion exchange, deionization |
| | Sulphates | Hard scales if Ca present | Deionization |
| | Chlorides | Priming, foaming | Deionization |
| | Fe, Mn | Rusting, resistance to HT | Aeration, filtration, ion exchange |
| | Silica | Scaling | Deionization, lime-soda process |

## Atmospheric Storage Tanks

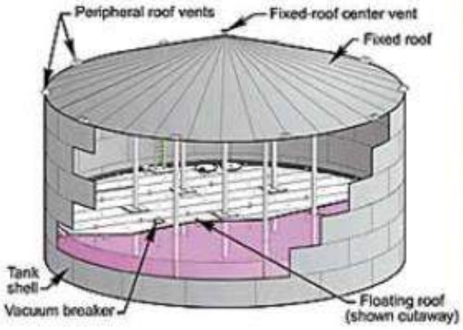
- Applied to tanks operating at or near atmospheric pressure.
- They are used to hold liquids which will not vaporize at ambient temperature.

**Atmospheric tanks are categorized primarily as follows:**

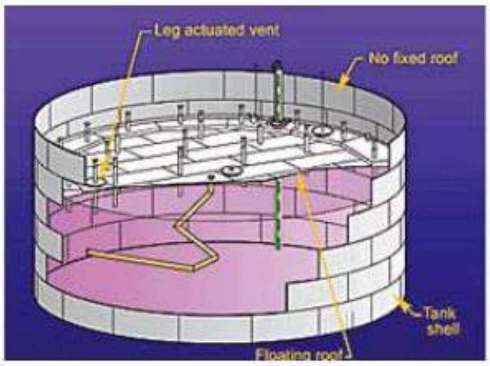
1. Open top (no roof)
   - ✓ Has no roof and may store or process non-volatile liquids such as water, brine, etc.
2. Fixed roof
   - ✓ Fixed roof tanks, such as cone roof or umbrella roof are used to store low vapor pressure liquids which will not vaporize at temperature below 120oF/50c.
   - ✓ Generally used for gas oil, water, chemicals.
3. Floating roof
   - ✓ Floating roof such as hard top pan and pontoon roof types eliminate the vapor space above the liquid, allows storage of higher vapor pressure materials.
   - ✓ Generally used for crude oil, gasoline, naphtha

**Tank Type:**

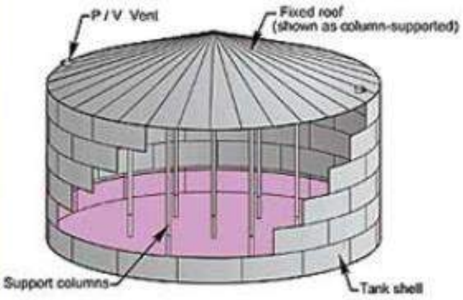
1. Fixed-roof tanks
2. External floating roof tanks
3. Internal floating roof tanks
4. Domed external floating roof tanks


Peripheral roof vents
Fixed-roof center vent
Fixed roof
Tank shell
Vacuum breaker
Floating roof (shown cutaway)

Internal floating roof tank

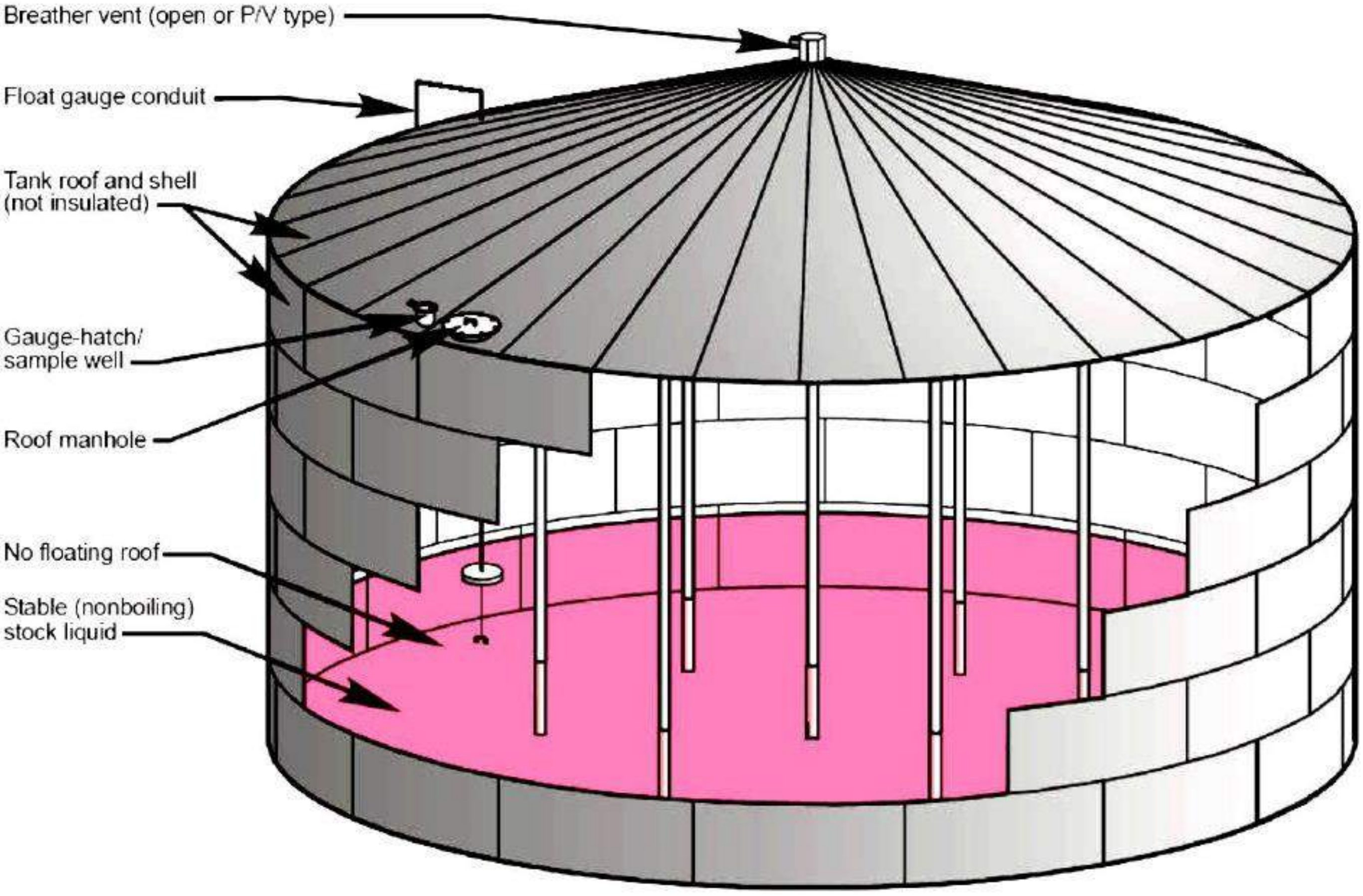

Leg actuated vent
No fixed roof
Tank shell
Floating roof

external floaitng rof tank


P / V Vent
Fixed roof (shown as column-supported)
Support columns
Tank shell

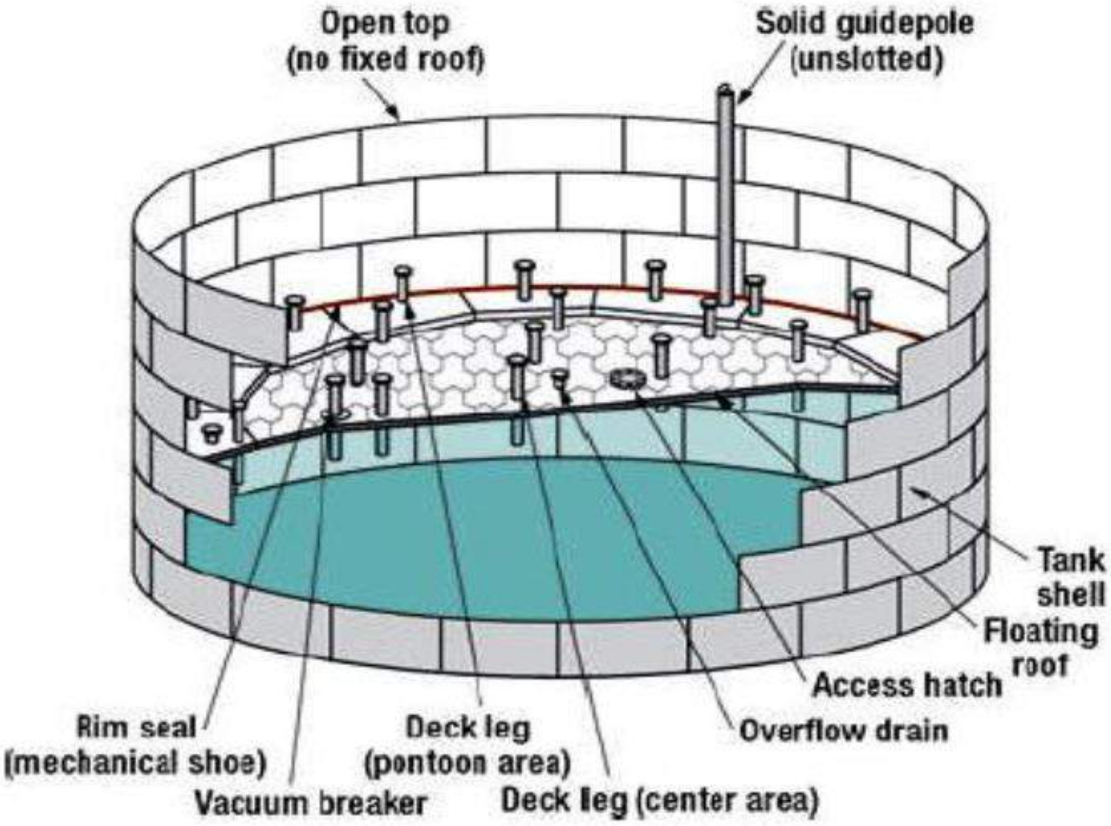
fixed roof tank

**Fix roof tank:**

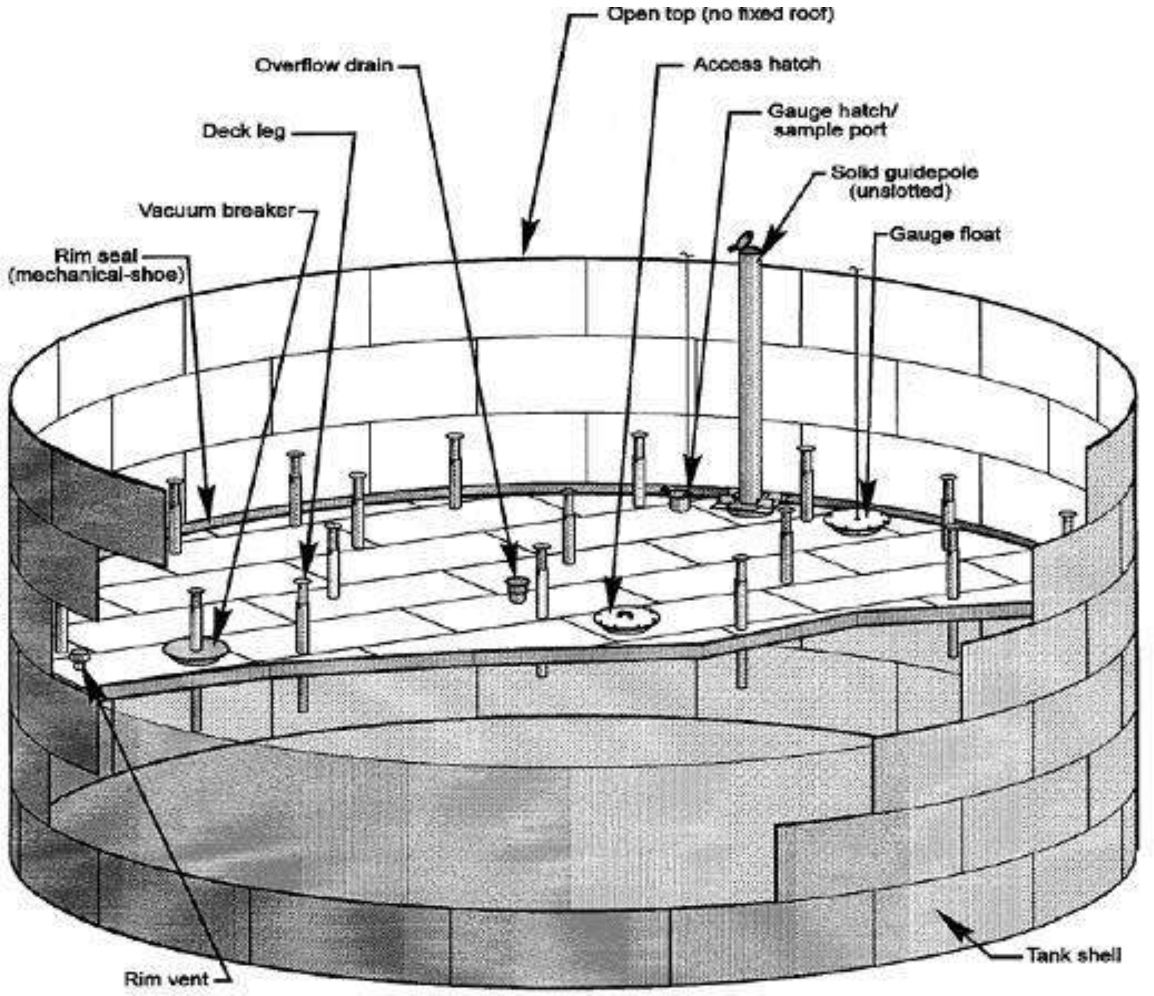

Breather vent (open or P/V type)
Float gauge conduit
Tank roof and shell (not insulated)
Gauge-hatch/ sample well
Roof manhole
No floating roof
Stable (nonboiling) stock liquid

**Fixed roof tank**

**External Floating Roof Tanks:**

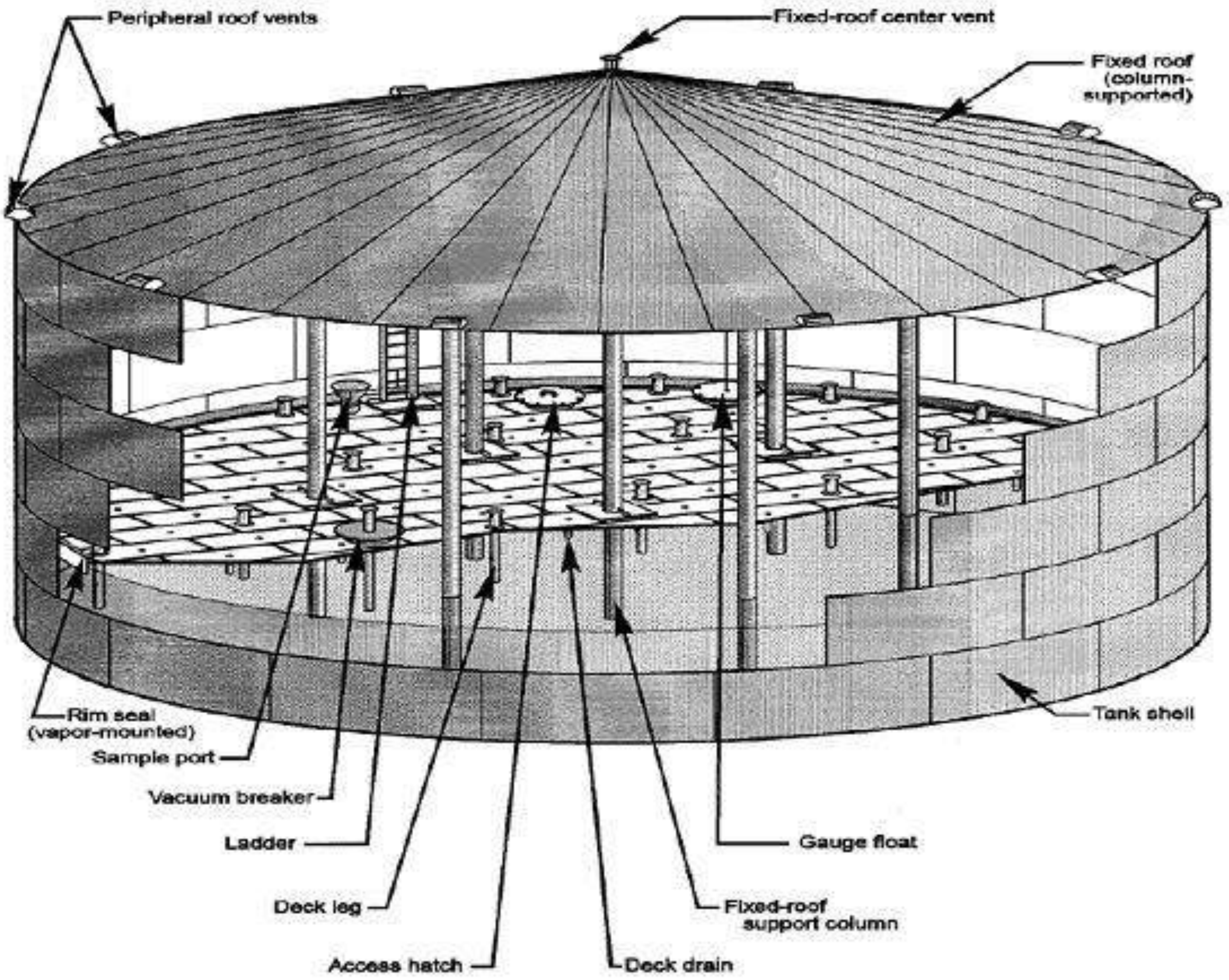

Open top
(no fixed roof)
Solid guidepole
(unslotted)
Tank
shell
Floating
roof
Access hatch
Overflow drain
Rim seal
(mechanical shoe)
Deck leg
(pontoon area)
Vacuum breaker
Deck leg (center area)

External Floating Roof Tanks (pontoon type)

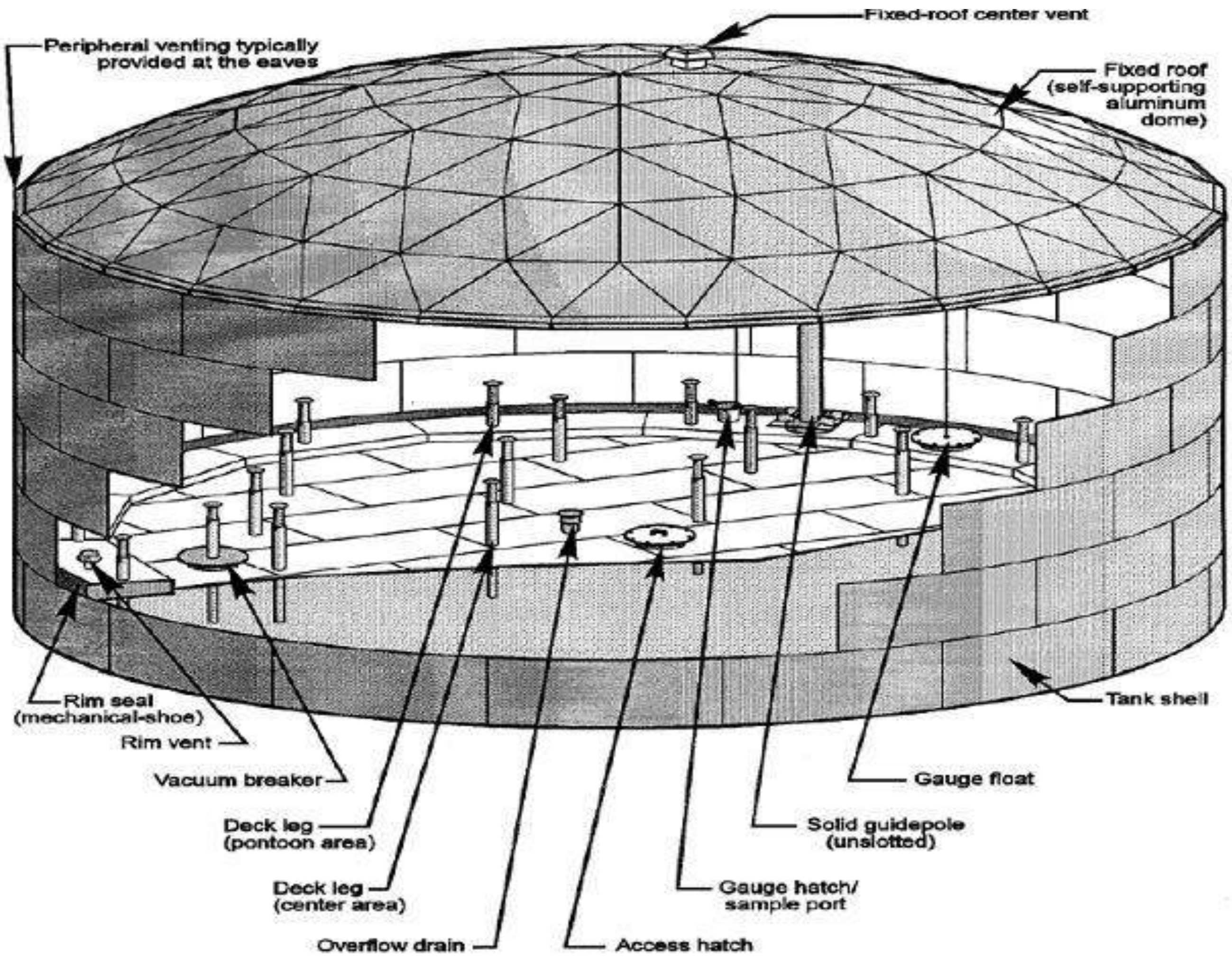

Open top (no fixed roof)
Overflow drain
Access hatch
Deck leg
Gauge hatch/
sample port
Solid guidepole
(unslotted)
Vacuum breaker
Gauge float
Rim seal
(mechanical-shoe)
Rim vent
Tank shell

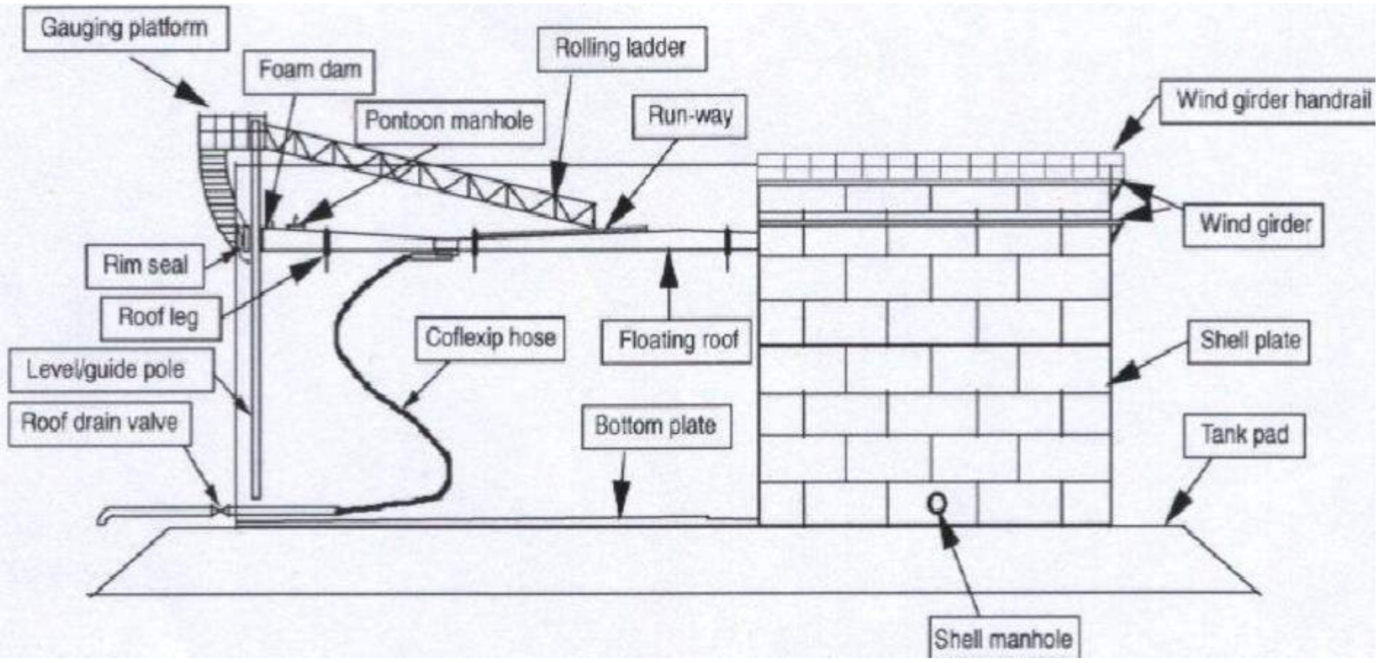
External Floating Roof Tanks (Double deck type)

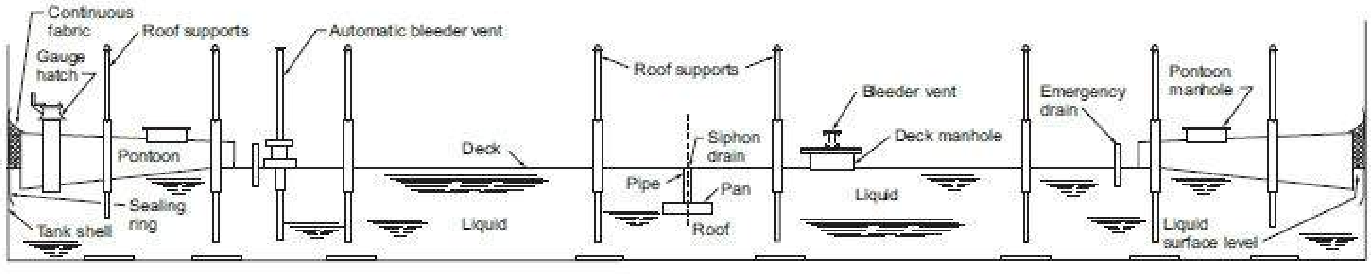
## Internal Floating Roof Tank:


Peripheral roof vents
Fixed-roof center vent
Fixed roof (column-supported)
Tank shell
Rim seal (vapor-mounted)
Sample port
Vacuum breaker
Ladder
Deck leg
Access hatch
Gauge float
Fixed-roof support column
Deck drain

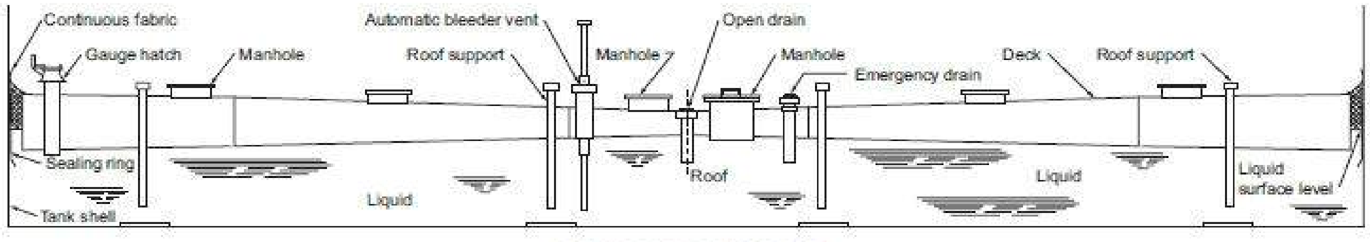
## Domed External Floating Roof Tanks


Fixed-roof center vent
Peripheral venting typically provided at the eaves
Fixed roof (self-supporting aluminum dome)
Tank shell
Rim seal (mechanical-shoe)
Rim vent
Vacuum breaker
Deck leg (pontoon area)
Deck leg (center area)
Overflow drain
Gauge float
Solid guidepole (unslotted)
Gauge hatch/ sample port
Access hatch


Gauging platform
Foam dam
Rolling ladder
Pontoon manhole
Run-way
Wind girder handrail
Wind girder
Rim seal
Roof leg
Level/guide pole
Coflexip hose
Floating roof
Shell plate
Roof drain valve
Bottom plate
Tank pad
Shell manhole


Continuous fabric
Roof supports
Automatic bleeder vent
Gauge hatch
Roof supports
Bleeder vent
Emergency drain
Pontoon manhole
Siphon drain
Deck manhole
Pontoon
Deck
Pipe
Pan
Liquid
Sealing ring
Tank shell
Liquid
Roof
Liquid surface level

PONTOON FLOATING ROOF


Continuous fabric
Automatic bleeder vent
Open drain
Gauge hatch
Manhole
Roof support
Manhole
Manhole
Deck
Roof support
Emergency drain
Sealing ring
Roof
Liquid
Liquid
Liquid surface level
Tank shell

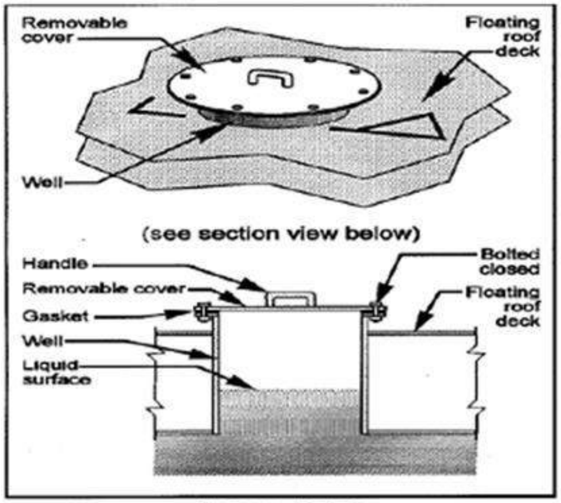
DOUBLE DECK FLOATING ROOF

**The most common components on the deck are described below.**

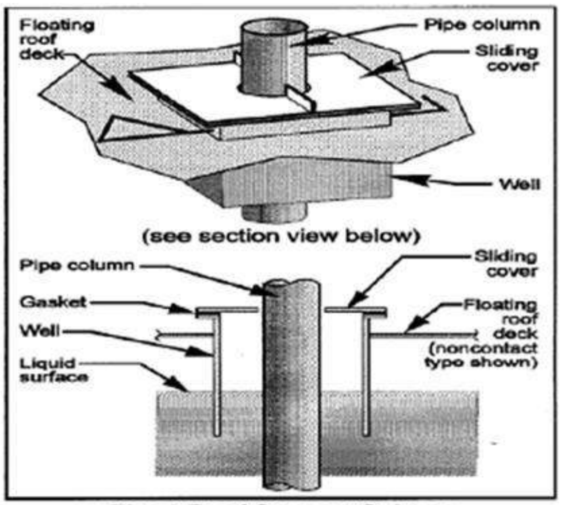
1. **Access hatches**. An access hatch is an opening in the deck with a peripheral vertical well that is large enough to provide passage for workers and materials through the deck for construction /maintenance / servicing. Attached to the opening is a removable cover that may be bolted and/or gasketed to reduce evaporative loss. On internal floating roof tanks with noncontact decks, the well should extend down into the liquid to seal off the vapor space below the noncontact deck.

2. **Gauge-floats**. A gauge-float is used to indicate the level of liquid within the tank. The float rests on the liquid surface and is housed inside a well that is closed by a cover. The cover may be bolted and/or gasketed to reduce evaporation loss. As with other similar deck penetrations, the well extends down into the liquid on noncontact decks in internal floating roof tanks.

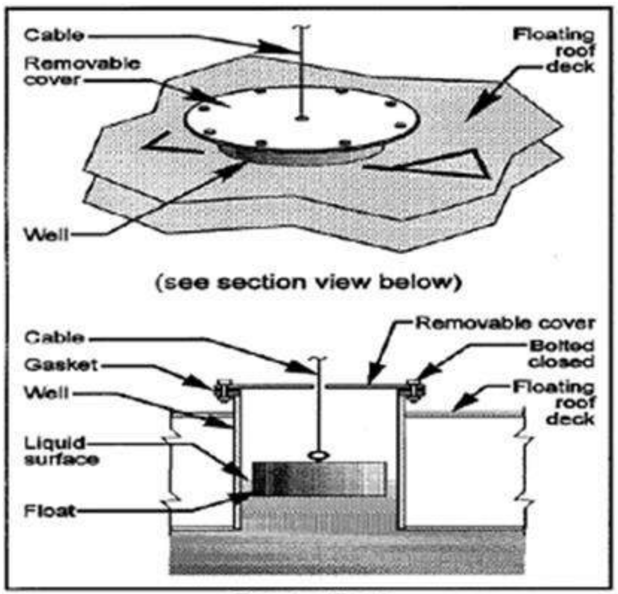
3. **Gauge-hatch/sample ports**. A gauge-hatch/sample port consists of a pipe sleeve equipped with a self-closing gasketed cover (to reduce evaporative losses) and allows hand-gauging or sampling of the stored liquid. The gauge-hatch/sample port is usually located beneath the gauge's platform, which is mounted on top of the tank shell. A cord may be attached to the self-closing gasketed cover so that the cover can be opened from the platform.


Removable cover
Floating roof deck
Well
(see section view below)
Handle
Bolted closed
Removable cover
Floating roof deck
Gasket
Well
Liquid surface

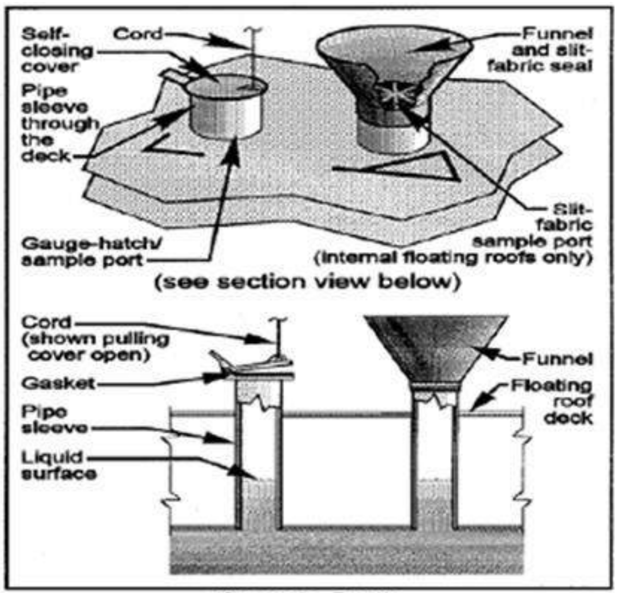
Access Hatch


Floating roof deck
Pipe column
Sliding cover
Well
(see section view below)
Pipe column
Sliding cover
Gasket
Floating roof deck (noncontact type shown)
Well
Liquid surface

Fixed-Roof Support Column

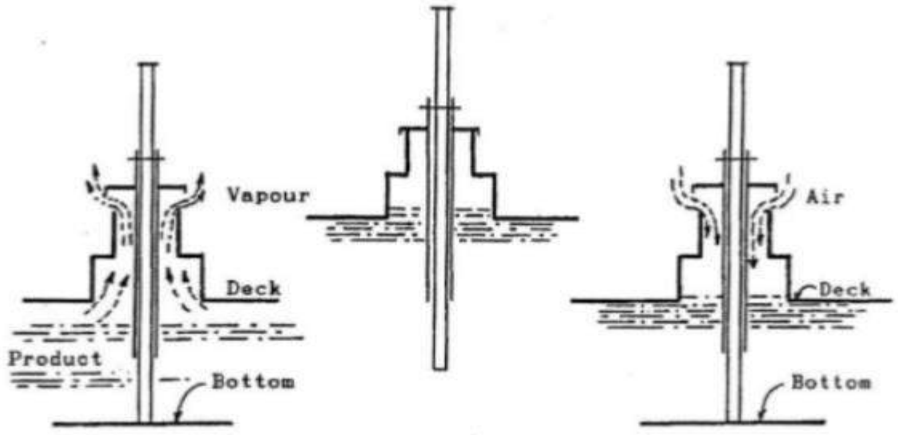

Cable
Removable cover
Floating roof deck
Well
(see section view below)
Cable
Gasket
Well
Liquid surface
Float
Removable cover
Bolted closed
Floating roof deck

Gauge float


Self-closing cover
Cord
Funnel and slit-fabric seal
Pipe sleeve through the deck
Slit-fabric sample port (internal floating roofs only)
Gauge-hatch/ sample port
(see section view below)
Cord (shown pulling cover open)
Gasket
Pipe sleeve
Liquid surface
Funnel
Floating roof deck

Sample Ports

4. **Rim vents**. Rim vents are used on tanks equipped with a seal design that creates a vapor pocket in the seal and rim area, such as a mechanical shoe seal. The vent is used to release any excess pressure or vacuum that is present in the vapor space bounded by the primary-seal shoe and the floating roof rim and the primary seal fabric and the liquid level. Rim vents usually consist of weighted pallets that rest on a gasket cover.

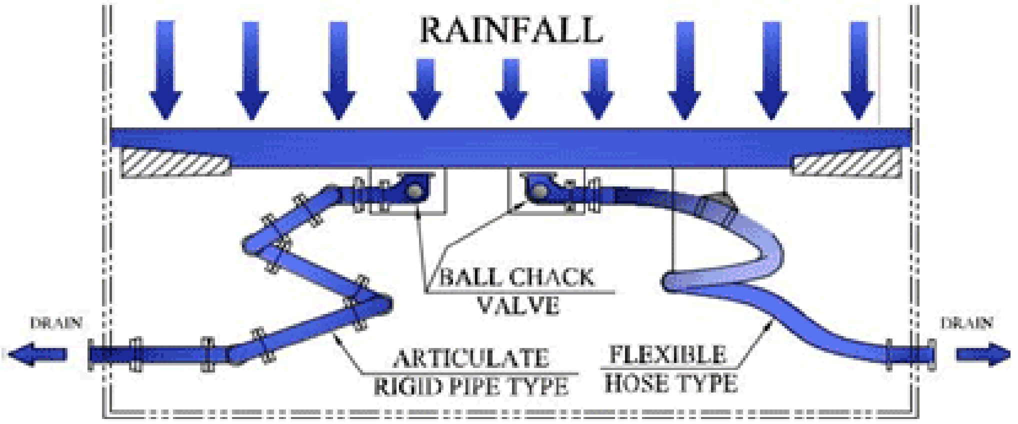

Vapour
Deck
Product
Bottom
Air
Deck
Bottom

Roof on support legs Tank filling

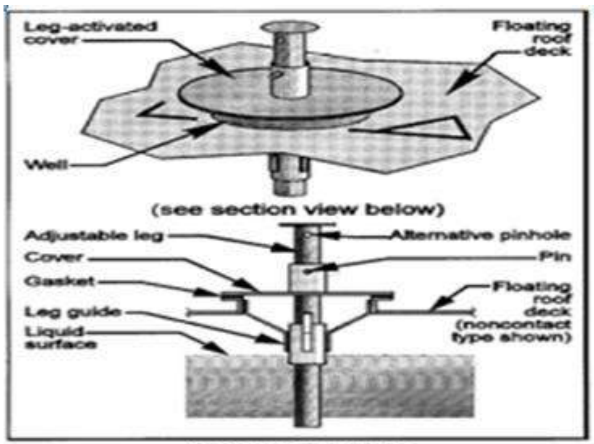
Roof floating

Roof on support legs Tank emptying

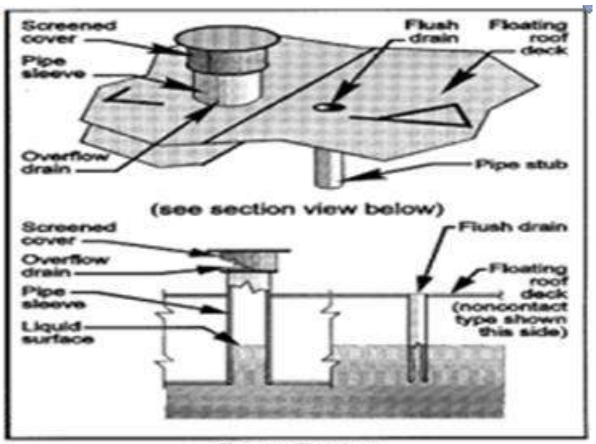
5. **Deck drains**. Currently two types of deck drains are in use (closed and open deck drains) to remove rainwater from the floating deck. Open deck drains can be either flush or overflow drains. Both types consist of a pipe that extends below the deck to allow the rainwater to drain into the stored liquid. Only open deck drains are subject to evaporative loss. Flush drains are flush with the deck surface. Overflow drains are elevated above the deck surface. Overflow drains are used to limit the maximum amount of rainwater that can accumulate on the floating deck, providing emergency drainage of rainwater if necessary. Closed deck drains carry rainwater from the surface of the deck though a flexible hose or some other type of piping system that runs through the stored liquid prior to exiting the tank. The rainwater does not come in contact with the liquid, so no evaporative losses result. Overflow drains are usually used in conjunction with a closed drain system to carry rainwater outside the tank.


RAINFALL
BALL CHACK VALVE
DRAIN
DRAIN
ARTICULATE RIGID PIPE TYPE
FLEXIBLE HOSE TYPE

6. **Deck legs**. Deck legs are used to prevent damage to fittings underneath the deck and to allow for tank cleaning or repair, by holding the deck at a predetermined distance off the tank bottom. These supports consist of adjustable or fixed legs attached to the floating deck or hangers suspended from the fixed roof. For adjustable legs or hangers, the load-carrying element passes through a well or sleeve into the deck. With noncontact decks, the well should extend into the liquid. Evaporative losses may occur in the annulus between the deck leg and its sleeve.


Leg-activated cover
Floating roof deck
Well
(see section view below)
Adjustable leg
Alternative pinhole
Cover
Pin
Gasket
Floating roof deck (noncontact type shown)
Leg guide
Liquid surface

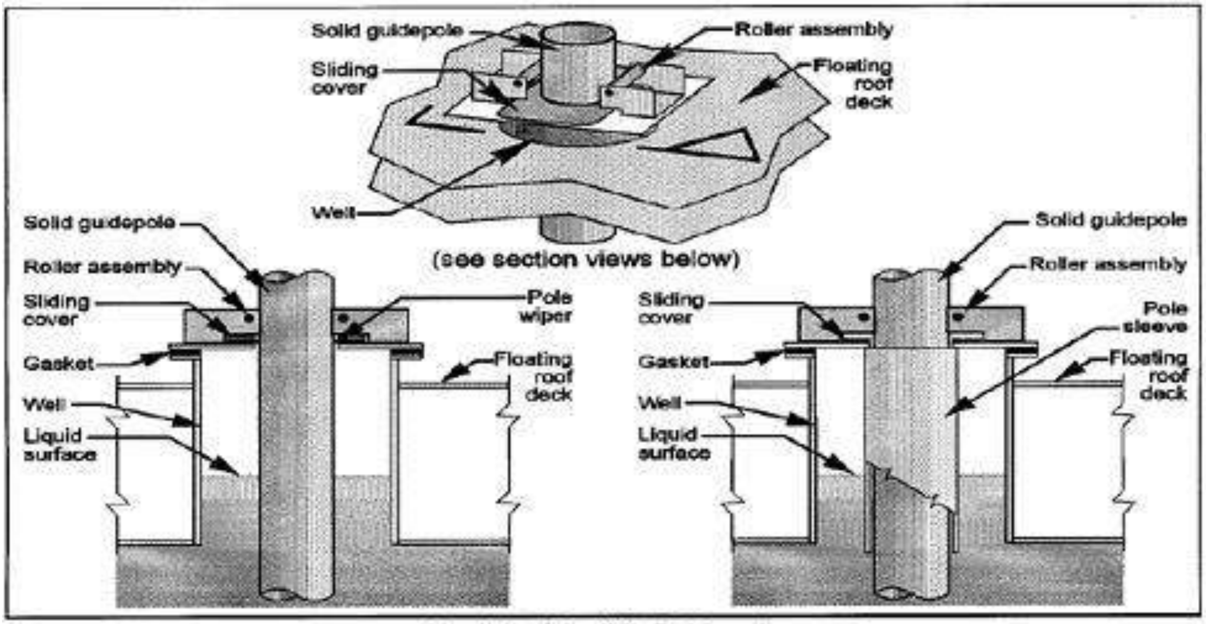
Vacuum Breaker


Screened cover
Pipe sleeve
Flush drain
Floating roof deck
Overflow drain
Pipe stub
(see section view below)
Screened cover
Flush drain
Overflow drain
Floating roof deck (noncontact type shown this side)
Pipe sleeve
Liquid surface

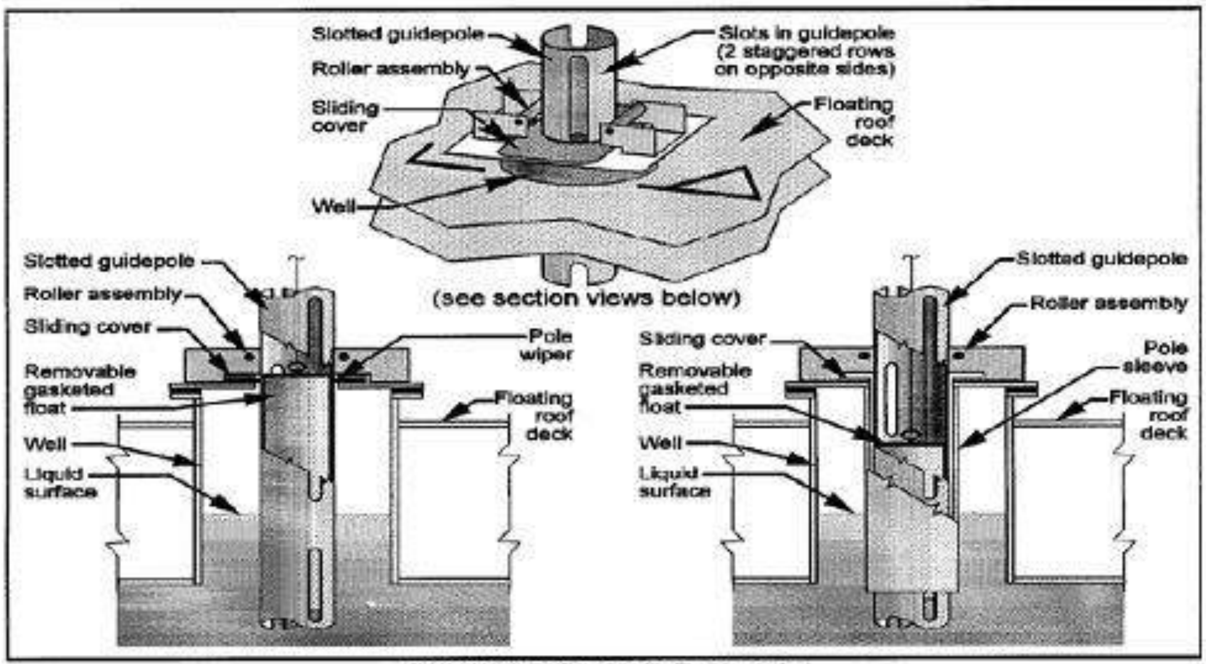
Deck Drains

7. **Unslotted guide poles and wells**. A guide pole is an anti rotational device that is fixed to the top and bottom of the tank, passing through a well in the floating roof. The guide pole is used to prevent adverse movement of the roof and thus damage to deck fittings and the rim seal system. In some cases, an unslotted guide pole is used for gauging purposes, but there is a potential for differences in the pressure, level, and composition of the liquid inside and outside of the guide pole.

8. **Slotted (perforated) guide poles and wells**. The function of the slotted guide pole is similar to the unslotted guide pole but also has additional features. Perforated guide poles can be either slotted or drilled hole guide poles. A typical slotted guide pole and well are shown in Figure .As shown in this figure, the guide pole is slotted to allow stored liquid to enter. The same can be accomplished with drilled holes. The liquid entering the guide pole is well mixed, having the same composition as the remainder of the stored liquid, and is at the same liquid level as the liquid in the tank. Representative samples can therefore be collected from the slotted or drilled hole guide pole. However, evaporative loss from the guide pole can be reduced by modifying the guide pole or well or by placing a float inside the guide pole. Guide poles are also referred to as gauge poles, gauge pipes, or stilling wells.


Solid guidepole
Roller assembly
Sliding cover
Floating roof deck
Well
(see section views below)
Solid guidepole
Roller assembly
Sliding cover
Pole wiper
Gasket
Floating roof deck
Well
Liquid surface
Solid guidepole
Roller assembly
Sliding cover
Pole sleeve
Gasket
Floating roof deck
Well
Liquid surface

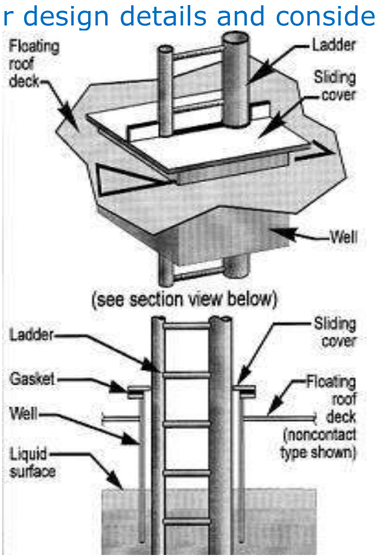
Unslotted (solid) Guidepole


Slotted guidepole
Slots in guidepole (2 staggered rows on opposite sides)
Roller assembly
Sliding cover
Floating roof deck
Well
(see section views below)
Slotted guidepole
Roller assembly
Sliding cover
Pole wiper
Removable gasketed float
Floating roof deck
Well
Liquid surface
Slotted guidepole
Roller assembly
Sliding cover
Pole sleeve
Removable gasketed float
Floating roof deck
Well
Liquid surface

Slotted (perforated) Guidepole

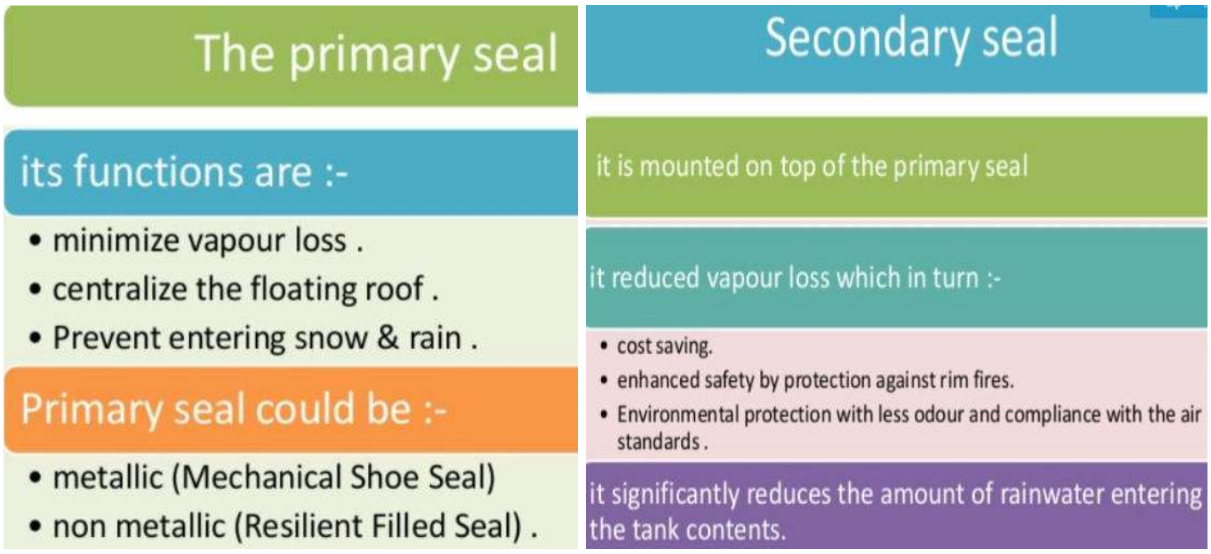
9**. Vacuum breakers**. A vacuum breaker equalizes the pressure of the vapor space across the deck as the deck is either being landed on or floated off its legs. the vacuum breaker consists of a well with a cover. Attached to the underside of the cover is a guided leg long enough to contact the tank bottom as the floating deck approaches. When in contact with the tank bottom, the guided leg mechanically opens the breaker by lifting the cover off the well; otherwise, the cover closes the well. The closure may be gasketed or ungasketed. Because the purpose of the vacuum breaker is to allow the free exchange of air and/or vapor, the well does not extend appreciably below the deck. Fittings used only on internal floating roof tanks include column wells, ladder wells, and stub drains.

1**. Columns and wells**. The most common fixed-roof designs are normally supported from inside the tank by means of vertical columns, which necessarily penetrate an internal floating deck. (Some fixed roofs are entirely self-supporting and, therefore, have no support columns.) Column wells are similar to unslotted guide pole wells on external floating roofs. Columns are made of pipe with circular cross sections or of structural shapes with irregular cross sections (built-up). The number of columns varies with tank diameter, from a minimum of 1 to over 50 for very large diameter tanks. The columns pass through deck openings via peripheral vertical wells. With noncontact decks, the well should extend down into the liquid stock. Generally, a closure device exists between the top of the well and the column. Several proprietary designs exist for this closure, including sliding covers and fabric sleeves, which must accommodate the movements of the deck relative to the column as the liquid level changes. A sliding cover rests on the upper rim of the column well (which is normally fixed to the deck) and bridges the gap or space between the column well and the column. The cover, which has a cut out, or opening, around the column slides vertically relative to the column as the deck raises and lowers. At the same time, the cover slides horizontally relative to the rim of the well. A gasket around the rim of the well reduces emissions from this fitting. A flexible fabric sleeve seal between the rim of the well and the column (with a cut out or opening, to allow vertical motion of the seal relative to the columns) similarly accommodates limited horizontal motion of the deck relative to the column.
2. **Ladders and wells**. Some tanks are equipped with internal ladders that extend from a manhole in the fixed roof to the tank bottom. The deck opening through which the ladder passes is constructed with similar design details and considerations to deck openings for column wells



3. **Stub drains**. Bolted internal floating roof decks are typically equipped with stub drains to allow any stored product that may be on the deck surface to drain back to the underside of the deck. The drains are attached so that they are flush with the upper deck. Stub drains are approximately 1 inch in diameter and extend down into the product on noncontact decks.
Deck seams in internal floating roof tanks are a source of emissions to the extent that these seams may not be completely vapor tight if the deck is not welded. Generally, the same loss mechanisms for fittings apply to deck seams. The predominant mechanism depends on whether or not the deck is in contact with the stored liquid. The deck seam loss equation accounts for the effects of all contributing loss mechanisms.

**Vapour mounted primary seal / secondary seal:**



The primary seal

its functions are :-

- minimize vapour loss .
- centralize the floating roof .
- Prevent entering snow & rain .

Primary seal could be :-

- metallic (Mechanical Shoe Seal)
- non metallic (Resilient Filled Seal) .

Secondary seal

it is mounted on top of the primary seal

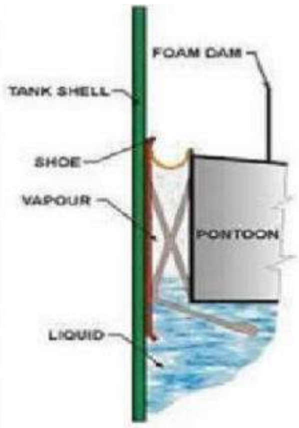
it reduced vapour loss which in turn :-

- cost saving.
- enhanced safety by protection against rim fires.
- Environmental protection with less odour and compliance with the air standards .

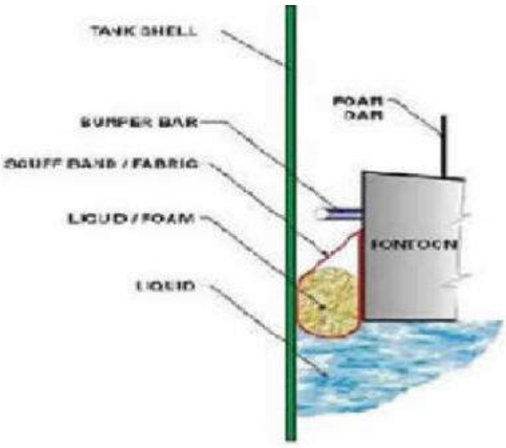
it significantly reduces the amount of rainwater entering the tank contents.

# Roof Seal Material

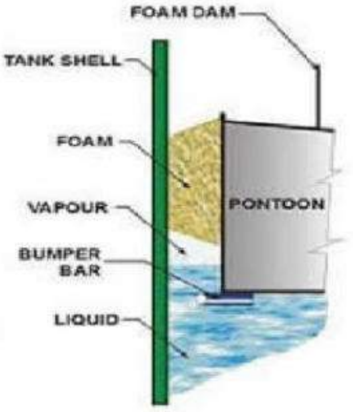
| Material | Resistance Against | | Flame Retardant? |
|---|---|---|---|
| | Hydrocarbons | UV light | |
| Vition ® (FPM)/ nylon (PA) | Very Good | Very Good | Yes |
| Teflon ® (PTFE)/ glass | Very Good | Very Good | Yes |
| Neoprene (CR)/ calcium silicate | Reasonable | Good | No |
| Polyurethane (EU)/ nylon (PA) or polyester (TPE-E) | Good | Good | No |
| PVC-nitrile (PVC-NBR)/ nylon (PA) or polyester (TPE-E) or glass | Good | Reasonable | No |
| Nitrile (NBR)/ Nylon (PA) or polyester (TPE-E) | Reasonable | Poor | No |


FOAM DAM
TANK SHELL
SHOE
VAPOUR
PONTOON
LIQUID

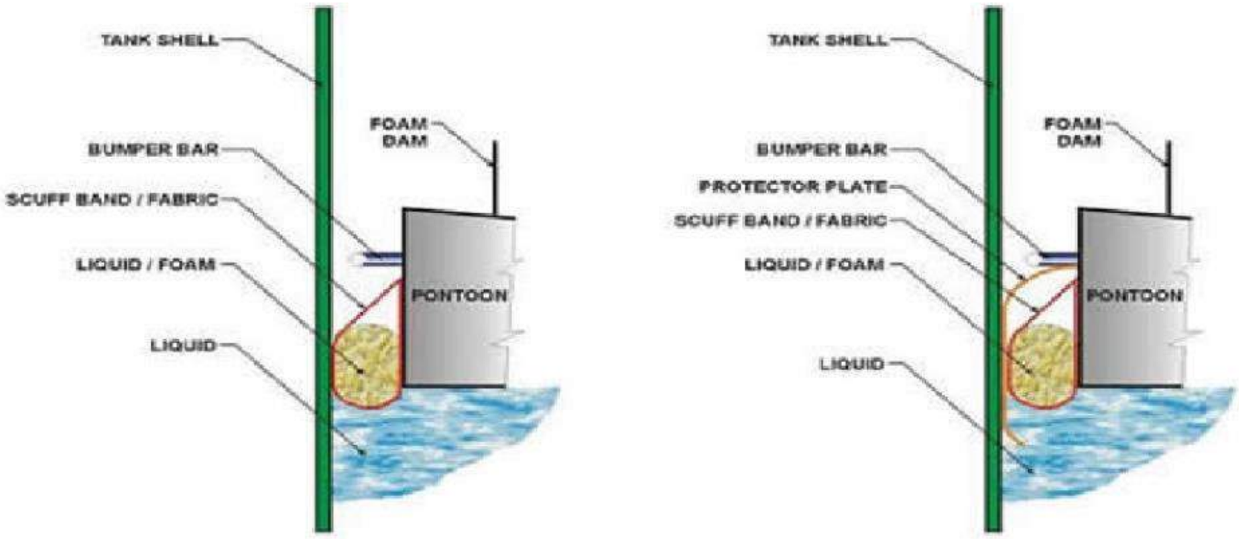
**Mechanical Shoe Seal**


TANK SHELL
FOAM DAM
BUMPER BAR
SCUFF BAND / FABRIC
LIQUID / FOAM
PONTOON
LIQUID

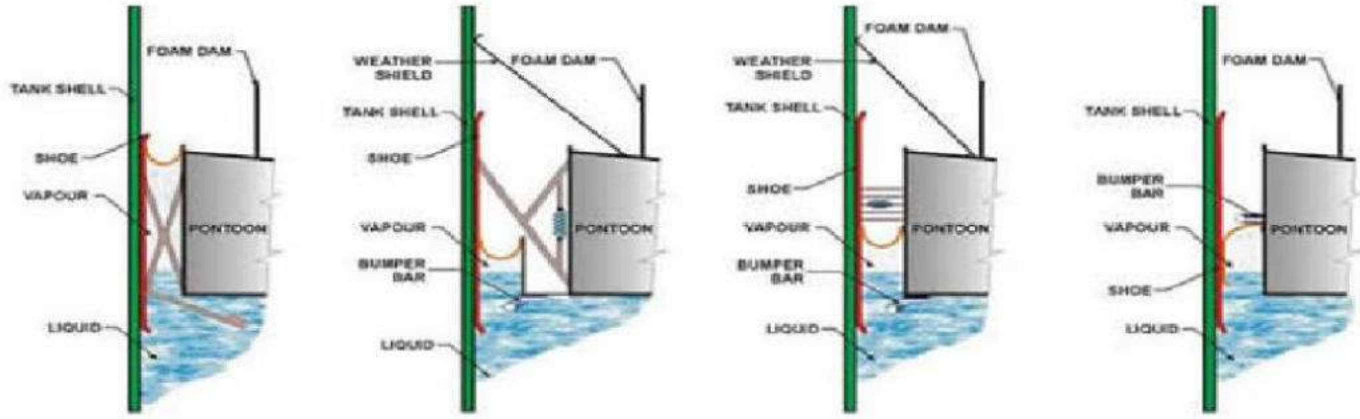
**Liquid-Mounted Foam Seal**


FOAM DAM
TANK SHELL
FOAM
PONTOON
VAPOUR
BUMPER BAR
LIQUID

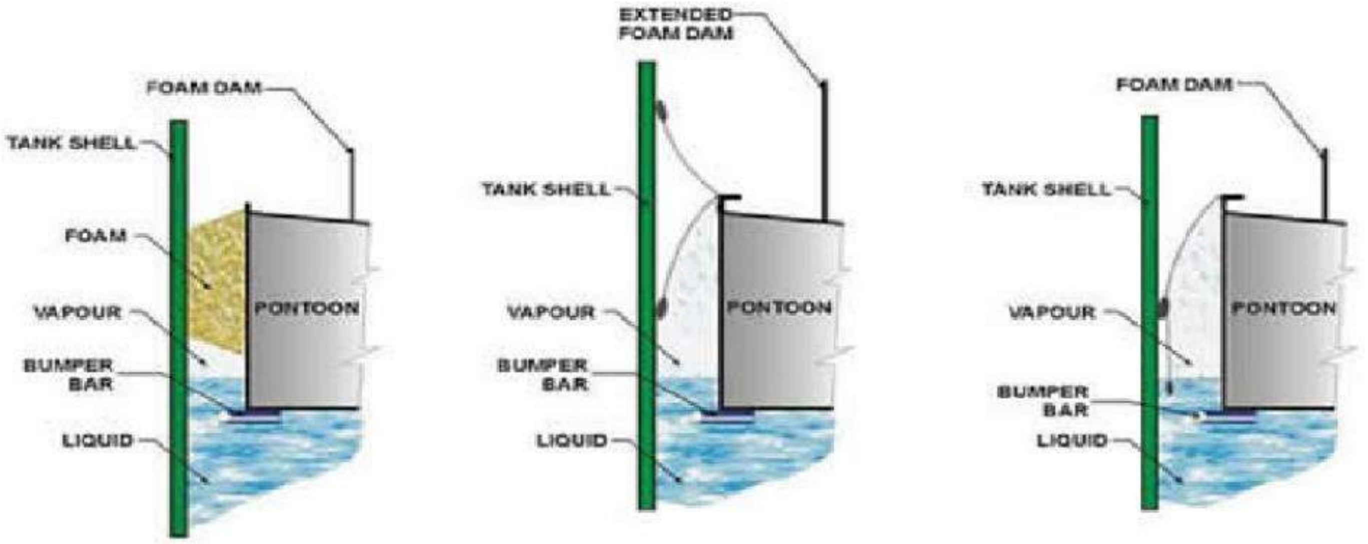
**Vapour-Mounted Seal**


TANK SHELL
FOAM DAM
BUMPER BAR
SCUFF BAND / FABRIC
LIQUID / FOAM
PONTOON
LIQUID
TANK SHELL
FOAM DAM
BUMPER BAR
PROTECTOR PLATE
SCUFF BAND / FABRIC
LIQUID / FOAM
PONTOON
LIQUID

Liquid Mounted Seals


FOAM DAM
TANK SHELL
SHOE
VAPOUR
PONTOON
LIQUID
WEATHER SHIELD
FOAM DAM
TANK SHELL
SHOE
VAPOUR
PONTOON
BUMPER BAR
LIQUID
FOAM DAM
WEATHER SHIELD
TANK SHELL
SHOE
VAPOUR
PONTOON
BUMPER BAR
LIQUID
FOAM DAM
TANK SHELL
BUMPER BAR
VAPOUR
PONTOON
SHOE
LIQUID

Mechanical Shoe Seals


FOAM DAM
TANK SHELL
FOAM
VAPOUR
PONTOON
BUMPER BAR
LIQUID
EXTENDED FOAM DAM
TANK SHELL
VAPOUR
PONTOON
BUMPER BAR
LIQUID
FOAM DAM
TANK SHELL
VAPOUR
PONTOON
BUMPER BAR
LIQUID

FOAM SEAL

DOUBLE WIPER

PRIMARY WIPER WITH SKIRT

Vapour Mounted Seals

The **rim seal** system is used to allow the floating roof to rise and fall within the tank as the liquid level changes. The rim seal system also helps to fill the annular space between the rim and the tank shell and therefore minimize evaporative losses from this area. A rim seal system may consist of just a primary seal or a primary and a secondary seal, which is mounted above the primary seal.
The **primary seal** serves as a vapor conservation device by closing the annular space between the edge of the floating deck and the tank wall. Three basic types of primary seals are used on external floating roofs: mechanical (metallic) shoe, resilient filled (non-metallic), and flexible wiper seals. Some primary seals on external floating roof tanks are protected by a weather shield. Weather shields may be of metallic, elastomeric, or composite construction and provide the primary seal with longer life by protecting the primary seal fabric from deterioration due to exposure to weather, debris, and sunlight. Internal floating roofs typically incorporate one of two types of flexible, product-resistant seals, .0resilient foam-filled seals or wiper seals. Mechanical shoe seals, resilient filled seals, and wiper seals.

### Tank Bottom Repair Work (Replacement of Annular, Sketch Plates & Patch Work)

- **ISOLATION**
    - 5) Isolation: De-pressurize pipelines and Isolate all valves of those pipelines connected with that tank.
    - 6) Empty the pipeline from the product and push it to the stripping line.
    - 7) Install the spades on upstream to blind the lines.
- **DE-GASSING**
    - 1) Open the man ways, keep it open 24 hours for natural degassing.
    - 2) Strip the remaining product using dewatering line and push it to the stripping line.
    - 3) After 24 hours start degassing with air ejectors.
    - 4) Once LEL become 0% then obtain confined space entry permit to enter inside tank for cleaning of tank bottom.
    - 5) Check VOC with the VOC gas monitor, if VOC is less than 15% can work without full face mask. But more than this level cleaning should be carried out with full face mask (organic cartridge).

- **TANK BOTTOM CLEANING**
  1) Cleaning team inside tank should have multi-gas detector for monitoring the LEL during cleaning.
  2) Removal of oily water and sludge.
  3) Wash the tank's bottom with liquid soap.
  4) Cleaning completed.
- **PAINT REMOVAL FROM TANK BOTTOM**
  1) Start blasting for removal of bottom plate old paint.
  2) Old paint removal completed.
- **MFL (MAGNETIC FLUX LEAK)**
  1) Scanning of whole tank bottom with MFL machine.
  2) UT Scanning for the critical zone (300mm area of annular plates towards shell), where MFL machine access is not possible.
  3) UT Scanning of plate joints area, where MFL machine cannot scan.
  4) MFL report will give complete information, where thickness is less, how many sketch plates need to replace and how much patches are required and of which size.
  5) Marking of sketch plates for replacement.
  6) Marking of patch plate location for on bottom plates.
  7) New annular plates are as per std / drawing
- **REPLACEMENT OF ANNULAR PLATES**

**1) ARRANGEMENTS FOR JACKING-UP SHELL**

1 Remove all the piping attached with the tank.
2 Remove or disconnect all the structure attached with the tank.
3 Disconnect all the suction / stripping / dewatering piping inside the tank from the shell or loosen their U-bolt fixed with the supports.
4 Preparatory work for jack-up the shell partially.
5 Fix base plate of 12mm with 200 H-beam (length 800mm).
6 Install 200mm H-beam on distance of 1.5 or 2 meters from each other in the circumference of the tank and keep the required space from tank should to the beam bottom to accommodate bottle jack of 25 tons for lifting of shell.
7 Prepare the lifting arrangement for ¼ portion of the tank.
8 This is partial shell lifting.
9 Shell jacking-up 30mm to 50mm only.
10 Before lifting the shell open the flashing of dome roof to check the integrity of the dome roof aluminium structure.
11 Exp : For 46 dia tank, 24 jacks are required to lift ¼ portion of the tank, keep some extra bottle jacks, in case if any jack damaged during lifting. Fabricate 22mm thick plates of size 1.5m x 1m (should be suitable in width to lay on tank shoulder).

**2) LIFTING OF SHELL**

1 Once preparation done for jacking-up the shell.
2 Cut the shell as per code API-653, ½ inch above the weld joint of annular to shell.
3 Well trained gas cutter should be used for cutting the shell to avoid uneven cutting. If cutting is smooth and good then can avoid lot grinding work for shell plate smoothness.
4 Before cutting the shell mark the reference points of the shell on the bottom plates and on the shell plates.
5 Better use jigs / fixture for cutting nozzle for accurate cutting.
6 Cut the shell ¼ portions and some extra to jack-up the shell 1/4 portion.
7 Install all the jacks under the beam fixed with tank shell.
8 Mark the reference point before jacking up the shell, and start jacking up slowly from centre area and then all jacking operators should start jacking up parallel.
9 Continue monitor the jacking height.
10 After completion of jacking up the tank, start drilling holes in annular plates to check presence of LEL or H2S.
11 After getting clearance from HSE that there is no LEL/H2S, then start cutting of annular plates.
12 Removal the existing annular plates for the specific lifted area.
13 Remove the existing sand up to 50mm.
14 Properly grind the shell bottom and make it even.
15 Refill the new silica sand or any approved sand as per client.
16 Installation of new fabricated annular plates.
17 Parallel lift the other ¼ portion of the tank and use the same sequence as described above.
18 Annular to annular joint is butt joint and need RT, PAUT (Phase Array Ultrasonic Test) can be done for these butt joints.
19 After completion of all annular to annular joints and its inspection (PAUT).
20 Jack down the shell and start fit-up shell to annular
21 Once root weld of the shell to annular completed for that specific area.
22 Do oil chalk test to ensure there is no leakage in the root.

23 Apply the chalk wet paste on the weld root in the tank and pour oil from outside the tank. Keep it for 4 hours to check the leakage.
24 Completion of welding shell to annular and annular to sketch.
25 If any sketch plate replacement is required replace it.
26 After completion of hot work joint inspection of TPI, Client & Contractor.
27 If any point raised during inspection can be marked at that time and rectified after completion of inspection.
28 Remove all the temporary attachments installed for jacking up the shell.
29 Tank released for painting.
30 Blasting of tank bottom as per painting standard SA 2.5. Painting system (as per std /drawing)

- **FFS (Fit For Service)**

**1) SHELL CUT PIECE**

1 As per API-653, if exemption of hydro test is required.
2 Then FFS test shall be carried out.
3 Shell piece 600x600mm need to cut and install new piece.
4 Existing cut piece required to send to laboratory for analysis to confirm that tank is fit for service.

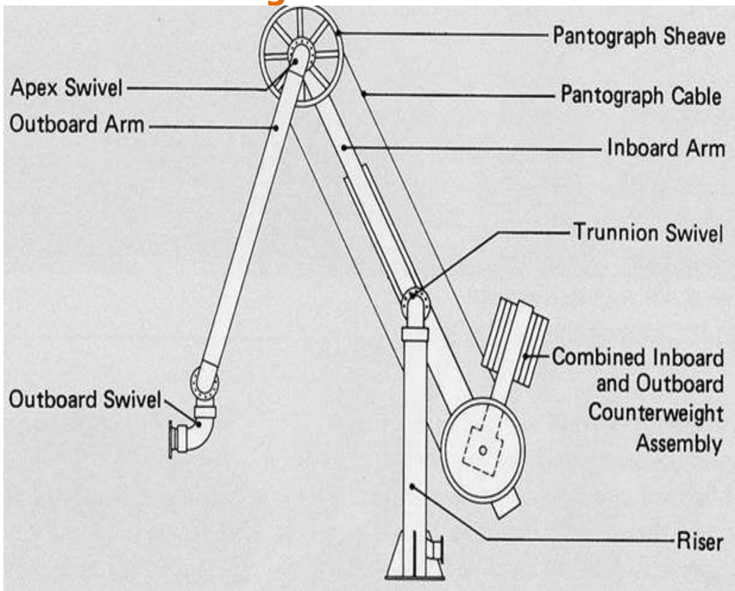
**Inspection points (API 650/653) regarding tank, inspection schedule normally every year & major inspection / repair at 05 yrs**

- Dyke wall (for any crack, pipe sleeve ...etc)
- Drain Pit ( civil / piping )
- Tank foundation
- Tank structure (ladder, plate form , railing ..etc..)
- External shell plate
- Bottom chime plate (tank toe) & peripheral seal
- Wind girder
- Top roof & Seal, earthing cable , vent , ladder , sampling hatch , water drain pipe /joints ..etc..
- Safety valve & device
- Fire system (piping, sprinkler, foam pourer .etc..)

**Inspection points (API 570) regarding piping, inspection schedule keep normally every year**

- Piping ( civil foundation / support )
- Piping structure ( pipe rack / support)
- Piping stress
- Piping thickness measurement
- Physical inspection for corrosion, paint, insulation, earthing cable..etc
- Valves inspection ( need to service / PM valve every year)
- Safety valve ( need to service / PM valve every 05 year)
- In tank farm piping –pig barrel & pig alert inspection

## Maintenance of Loading Arm:


Pantograph Sheave
Apex Swivel
Pantograph Cable
Outboard Arm
Inboard Arm
Trunnion Swivel
Combined Inboard and Outboard Counterweight Assembly
Outboard Swivel
Riser

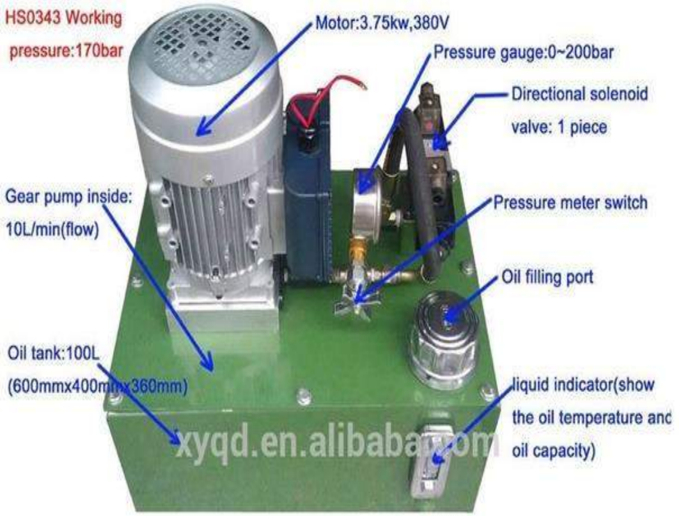
### Main Components of Loading Arm:

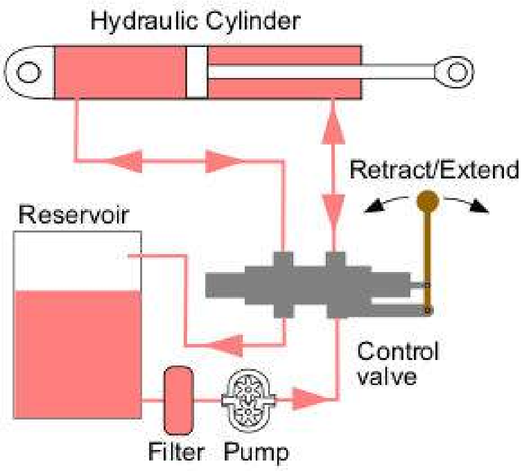
- Inboard Arm
- Outboard Arm
- Riser pipe
- Counter balance weight
- Connection Flange / QCDC
- Swivel Joints
- Emergency Release Coupling
- Hydraulic System
- Hydraulic hoses

### Preventive Maintenance / Overhaul (normally every 02 year)

- Check foundation
- Overhaul / inspection of Swivel Joint (greasing if required)
- Checking locking device (greasing if required)
- Hydraulic Equipment & power pack
  - ✓ Replacement of hydraulic oil & clean oil sump
  - ✓ Check hydraulic cylinder
  - ✓ Check balancing weight
  - ✓ Check or replace hydraulic hose
  - ✓ Replacement /clean of filter
  - ✓ Check pump
  - ✓ Check regulator / solenoid valve
- Wire Rope & fitting (greasing if required)
- Check sheave

### Hydraulic Equipment / power pack & circuit: (below exmp.)


HS0343 Working pressure:170bar
Motor:3.75kw,380V
Pressure gauge:0~200bar
Directional solenoid valve: 1 piece
Pressure meter switch
Gear pump inside: 10L/min(flow)
Oil filling port
Oil tank:100L (600mmx400mmx360mm)
liquid indicator(show the oil temperature anc oil capacity)
xyqd.en.alibaba.com


Hydraulic Cylinder
Retract/Extend
Reservoir
Control valve
Filter
Pump

- A **hydraulic reservoir** (or tank) which holds the enclosed oil. This is a storage unit designed with enough volume for the oil in the pipes to drain into it. They also ensure this oil is stored and maintained in the best possible condition. Reservoirs will come in different sizes. Common auxiliaries for a reservoir include filler/breathers and drain ports, level gauge, level switches and inspection covers.
- **Regulators** that control and maintain the amount of pressure that the hydraulic power pack delivers.

- **Pressure Supply lines and Relief lines**. The supply line supplies fluid under pressure to the pump and the relief lines relieve pressure between the pump and the valves. The relief lines also control the direction of flow through the system.
- **Motor** to power a pump
- A **pump** to perform two actions. Firstly, it creates a vacuum at the pump inlet and with the help of atmospheric pressure, forces fluid from the reservoir into the inlet line. This fluid is then fed to the pump. The pump then delivers this fluid to the pump outlet and force feeds it into the hydraulic system.
- Some of the important factors that influence a hydraulic power unit's performance are pressure limits, power capacity, and reservoir volume. In addition, its physical characteristics including size, power supply, and pumping strength are also significant considerations. Reputed suppliers take great care to ensure that a large, durable hydraulic power unit is built for functioning under a range of environmental conditions.
- **Filters:** Filtration is a critical part of a hydraulic power pack, ensuring wear is minimized and efficiencies are maintained. Basic suction strainers do not allow large contaminants to enter the pump. Pressure filters are normally configured at the pump outlet and ensure only filtered oil enters the hydraulic system. Contamination within the system is filtered out by the return filter before it enters the hydraulic reservoir.
- **Pressure Control valves** that limit or control the hydraulic pressure within the hydraulic system.
- **Directional Control hydraulic valves** (manual, electrical, pneumatic or hydraulic operated) direct the oil flow around the system to operate actuators, cylinders or other functions.
- **Cooling** is another other key consideration, where efficiencies within a system or machine will produce heat in the oil; this must be cooled to ensure long life and high-efficiency.
- **Accumulators:** These are containers that can be attached to the hydraulic actuators. They collect oil from the pump and are intended to build and maintain fluid pressure to supplement the motor pumping system.
- **Coolers and Heaters:** As part of the temperature regulation process, an air cooler can be installed near or behind the filter unit to prevent temperatures from rising above operational parameters. Likewise, a heating system, such as an oil-based heater, can be used to elevate temperatures when necessary.
- **Power Unit Controllers:** The hydraulic controller unit is the operator interface containing power switches, displays, and monitoring features. It is necessary for installing and integrating a power unit into a hydraulic systems, and can usually be found wired into the power unit. Oil level and temperature protection switch, Pressure switches and filter clogging switches are quite common.

## DEFINATION :

- **Abrasive / abrasion**
  A hard and wear-resistant material that is used to wear, grind or cut away other material.
- **Adhesive** a substance that bonds together the surfaces of two other materials
- **Alloy** a metallic solid or liquid formed from an intimate combination of two or more elements.
- **Absolute Humidity** Measurement of atmospheric humidity. Absolute humidity is the mass of water vapor in a given volume of air. Normally expressed in grams of water vapor per cubic meter of atmosphere at a specific temperature.
- **Absolute Zero** Temperature of -273.15° Celsius. At this temperature atomic motion stops.
- **Absorption (Atmospheric)** Atmospheric absorption is defined as a process in which solar radiation is retained by a substance and converted into heat energy. The creation of heat energy also causes the substance to emit its own radiation. In general, the absorption of solar radiation by substances in the Earth's atmosphere results in temperatures that get no higher than 1800° Celsius. According to Wien's Law, bodies with temperatures at this level or lower would emit their radiation in the long wave band.
- **Adiabatic** A process in which heat does not enter or leave a system. In the atmospheric sciences, adiabatic processes are often used to model internal energy changes in rising and descending parcels of air in the atmosphere. When a parcel of air rises it expands because of a reduction in pressure. If no other non-adiabatic processes occur (like condensation, evaporation and radiation), expansion causes the parcel of air to cool at a set rate of 0.98° Celsius per 100 meters. The opposite occurs when a parcel of air descends in the atmosphere. The air in a descending parcel becomes compressed. Compression causes the temperature within the parcel to increase at a rate of 0.98° Celsius per 100 meters
- **Alkaline** (1) Having a pH greater than 7. (2) Substance that releases hydroxyl ions ($OH^-$).
- **Atom** Smallest unit of an element that still maintains its chemical characteristics.
- **Atomic Energy** - released from an atomic nucleus because of a change in its subatomic mass.
- **Atomic Mass Number** Combined number of an atom's protons and neutrons.
- **Atomic Weight** Combined weight of an atom's electrons, protons, and neutrons.
- **actuator** A device responsible for actuating a mechanical device such as a control valve.
- **agglomeration** Any process for converting a mass of relatively fine solid material into a mass of larger lumps.
- **ambient air** 1. Air to which the sensing element is normally exposed. 2. The air that surrounds the equipment. The standard ambient air for performance calculations is air at 80°F, 60% relative humidity, and a barometric pressure of 29.921 in. Hg, giving a specific humidity of 0.013 lb of water vapour per lb of air.
- **ambient conditions** The conditions (pressure, temperature, etc.,) of the medium surrounding a given device or equipment.
- **anti surge control -**Control by which the unstable operating mode of compressors known as "surge" is avoided.
- **as built** A document revision that includes all modifications performed as a result of actual fabrication or installation.
- **austenitic stainless steel** An alloy of iron containing at least 12% Cr plus sufficient Ni (or in some specialty stainless steels, Mn) to stabilize the face centered cubic crystal structure of iron at room temperature.

- **axial fan** Consists of a propeller or disc type of wheel within a cylinder discharging the air parallel to the axis of the wheel.
- **axial flow** Describing a machine such as a pump or compressor in which the general direction of fluid flow is parallel to the axis of its rotating shaft.
- **Brass** a copper-rich copper-zinc alloy
- **Brazing** a metal joining technique that uses a molten filler metal alloy having a melting temperature greater than about 425 ° C.
- **Bronze** a copper-rich copper-tin alloy.
- **Bar** A unit of measurement for quantifying force. Equivalent to 1,000,000 dynes per square centimeter
- **Brine** Seawater with a salinity greater than 35 parts per thousand. Usually occurs in isolated bodies of seawater that have high amounts of water loss due to evaporation.
- **British Thermal Unit (Btu)** Measurement unit for heat. It is the amount of energy required to raise the temperature of one pound of water one degree from 62 to 63° Fahrenheit. One Btu is equal to 252 calories and to 1055 joules.
- **baffle** A plate or vane, plain or perforated, used to regulate or direct the flow of fluid.
- **bandwidth** The difference, expressed in hertz, between the two boundaries of a frequency range.
- **barometric pressure** Atmospheric pressure as determined by a barometer usually expressed in inches of mercury.
- **blowdown** 1. In a safety valve, the difference between opening and closing pressures. 2. In a steam boiler, the practice of periodically opening valves attached to the bottom of steam drums and water drums, during boiler operation, to drain off accumulations of sediment.
- **bomb calorimeter** An apparatus for measuring the quantity of heat released by a chemical reaction; it consists of a strong walled metal container (bomb) immersed in about 2.5 liters of water in an insulated container; a sample is sealed in the bomb, the bomb immersed, the reaction started by remote control, and the heat released measured by observing the rise in temperature of the water bath.

- **Bourdon tube** A pressure sensing element consisting of a twisted or curved tube of noncircular cross section which tends to be straightened by the application of internal pressure. Also known as "Bourdon element" when used in a "Bourdon pressure gauge."
- **buoyancy** The tendency of a fluid to lift any object submerged in the body of the fluid; the amount of force applied to the body equals the product of fluid density and volume of fluid displaced.
- **byte** A sequence of adjacent binary digits (bits) operated upon as a unit and usually shorter than a word, commonly an eight bit segment of a computer word. A byte can be used to store one ASCII character.
- **BLEEDING** Divert or release a small portion of the material contained in a line or vessel, usually by opening a valve slightly
- **BOMB** A small pressure vessel, such as used for taking samples of HP gases and LPG.
- **BUFFER** 1.A vessel for temporary storage of liquid (buffer drum).
  2.A chemical used to maintain another within set limits of (e.g.) pH.
- **Barring** Manually rotate the fly wheel for compressors to ensure oil circulation throughout the shaft.

- **CORROSION** The gradual eating away of metallic surfaces as the result of chemical action such as oxidation. It is caused by corrosive agents such as acids.
- **Cast Iron** a ferrous alloy with carbon content between 2 and 4.5 wt%.
- **Cathodic Protection** a means of corrosion prevention whereby electrons are supplied to the structure to be protected from an external source such as another more reactive metal or a dc power supply.
- **Cold Working** the plastic deformation of a metal at a temperature below that at which it recrystallizes.
- **Calorie** Quantity of energy. Equals the amount of heat required to raise 1 gram of pure water from 14.5 to 15.5° Celsius at standard atmospheric pressure.
- **Capillary Action** Movement of water along microscopic channels. This movement is the result of two forces: the adhesion and absorption of water to the walls of the channels; and cohesion of water molecules to each other.
- **Carbonation** Is a form of chemical weathering where carbonate and bicarbonate ions react with minerals that contain calcium, magnesium, potassium, and sodium.
- **Condensation** The change in state of matter from vapor to liquid that occurs with cooling. Usually used in meteorology when discussing the formation of liquid water from vapor. This process releases latent heat energy to the environment.
- **Conduction** Conduction consists of energy transfer directly from atom to atom and represents the flow of energy along a temperature gradient
- **Convection** Convection involves the transfer of heat energy by means of vertical mass motions through a medium.
- **Cation** An ion carrying a positive atomic charge.
- **Cation Exchange** Chemical trading of cations between the soil minerals and organic matter with the soil solution and plant roots.
- **Calorie** The mean calorie is 1/100 of the heat required to raise the temperature of 1 gram of water from 0°C to 100°C at a constant atmospheric pressure. Also defined as 3600/860 joules, a joule being the amount of heat produced by a watt in one second.
- **calorific value** The number of heat units liberated per unit of quantity of a fuel burned in a calorimeter under prescribed conditions.
- **Calorimeter** 1. A device for determining the amount of heat liberated during a chemical reaction, change of state or dissolution process. 2. Apparatus for determining the calorific value of a fuel.
- **Capacitor** A device used for storing an electrical charge.
- **cavitation** A two stage phenomenon of liquid flow. The first stage is the formation of voids or cavities within the liquid system; the second stage is the collapse or implosion of these cavities back into an all liquid state.
- **cavitation erosion** Progressive removal of surface material due to localized hydrodynamic impact forces associated with the formation and subsequent collapse of bubbles in a liquid in contact with the damaged surface. Also known as "cavitations damage"; "liquid erosion failure."
- **Celsius** A scale for temperature measurement based on the definition of 0°C and 100°C as the freezing point and boiling point, respectively, of pure water at standard pressure.
- **centipoise (cp)** A unit of viscosity which is equal to 0.01 poise. centistokes (cs) A cgs unit of kinematics viscosity in customary use, equal to the kinematics viscosity of a fluid having a dynamic viscosity of 1 centipoise and a density of 1 gram per cubic centimeter.
- **centrifugal force** A force acting in a direction along and outward on the radius of turn for a mass in motion.
- **check valve** A flow control device that permits flow in one direction and prevents flow in the opposite direction.
- **circuit breaker** A device designed to allow manual opening and closing of a circuit and also to open the circuit automatically on a predetermined overload of current without damage to itself.
- **combustible gas** Any flammable or combustible gas or vapour (but not atomized liquid) that can, in sufficient concentration by volume in air, become the fuel for combustion.
- **Condensate** 1. The liquid product of a condensing cycle. 2. A light hydrocarbon mixture formed by expanding and cooling gas in a gas-recycling plant to produce a liquid output.
- **condensate trap** 1. A device to separate saturated water from steam in a pipe or piece of process equipment. 2. A device used to trap and retain condensate in a measurement impulse line to prevent hot vapours from reaching the instrument

- **CALIBRATION** The determination of fixed reference points on the scale of any instrument by comparison with a known standard and the subsequent subdivision or graduation of the scale to enable measurements in definite units to be made with it. Also the process of measuring or calculating the volumetric contents or capacity of a receptacle.
- **CATALYST** In technology this word means a substance added to a system of reactants which will accelerate the desired reactions, while emerging virtually unaltered from the process. The catalyst allows the reaction to take place at a temperature at which the uncatalyzed reaction would proceed too slowly for practical purposes. Used extensively in secondary processes.
- **condition monitoring system** A system designed to monitor the condition of a machine or process.
- **conductor** Any material through which electrical current can flow.
- **Conductivity :** Conductivity is basically an indicator of how much inorganic salts are present in a solution. More are inorganic salts, more is the conductivity and vice versa
- **damper** A device for introducing a variable resistance for regulating the volumetric flow of gas or air
- **density** 1. The mass of a unit volume of a liquid at a specified temperature. The units shall be stated, such as kilograms per meter3. 2. Closeness of texture or consistency. 5. Degree of opacity often referred to as "optical density".
- **desuperheater** Equipment used to remove superheat from steam, usually by the injection of water.
- **detergent** A natural material or synthetic substance having the soap like quality of being able to emulsify oil and remove soil from a surface.
- **diaphragm** A sensing element consisting of a thin, usually circular, plate which is deformed by pressure differential applied across the plate.
- **diffuser** A duct, chamber or enclosure in which low pressure, high velocity flow of a fluid, usually air, is converted to high pressure, low velocity flow.
- **diffusion** Migration of atoms, molecules or ions spontaneously, under the driving force of compositional differences, and using only the energy of thermal excitation to cause atom movements.—or-- mass transport by atomic motion.
- **dilution** Adding solvent to a solution to lower its concentration –or-- A liquid used to dilute or thin out another liquid
- **displacement** 1. The change in position of a body or point with respect to a reference point. 2. The volume swept out by a piston as it moves inside a cylinder from one extreme of its stroke to the other extreme.
- **distillation** vaporization of a substance with subsequent recovery of the vapour by condensation.
- **distributed control system (DCS)** Instrumentation system consisting of input/output devices, control devices and operator interface devices which in addition to executing the stated control functions also permits transmission of control, measurement, and operating information to and from multiple locations, connected by a communication link.
- **dry bulb temperature** The temperature of the air indicated by thermometer not affected by the water vapour content of the air.
- **Drawing** a deformation technique used to fabricate metal wire and tubing. Deformation is accomplished by pulling the material through a die by means of a tensile force applied on the exit side.
- **Ductility** a measure of a material's ability to undergo appreciable plastic deformation before fracture.
- **Density** (**of Matter**) Refers to the quantity of mass per unit volume. For gases, density involves the number of atoms and molecules per unit volume.
- **Dew Point** Dew point is the temperature at which water vapor saturates from an air mass into liquid or solid usually forming rain, snow, frost or dew. Dew point normally occurs when a mass of air has a relative humidity of 100%. If the dew point is below freezing, it is referred to as the frost point.
- **Dry-Bulb Thermometer** Thermometer on a psychrometer used to determine current air temperature. This measurement and the reading from a wet-bulb thermometer are then used for the determination of relative humidity or dew point from a psychrometric table.
- **Extrusion** a forming technique whereby a material is forced, by compression, through a die orifice
- **Elastic Deformation** Change in the shape of a material as the result of the force of compression or expansion. Upon release of the force, the material returns to its original shape. Also called plastic deformation.
- **Electron** A sub-particle of an atom that contains a negative atomic charge.
- **Element** A molecule composed of one type of atom. Chemists have recognized or created 112 different types of elements.
- **Energy** Is defined as the capacity for doing work. Energy can exist the following forms: radiation; kinetic energy; potential energy; chemical energy; atomic energy; electromagnetic energy; electrical energy; and heat energy.
- **Evaporation** Evaporation can be defined as the process by which liquid water is converted into a gaseous state. Evaporation can only occur when water is available. It also requires that the humidity of the atmosphere be less than the evaporating surface (at 100% relative humidity there is no more evaporation). The evaporation process requires large amounts of energy. For example, the evaporation of one gram of water at a temperature of 100° Celsius requires 540 calories of heat energy (600 calories at 0° Celsius).
- **economiser** Heat exchanger used to recover excess thermal energy from process streams.
- **efficiency** 1. The efficiency of a boiler is the ratio of heat absorbed by water and steam to the heat equivalent of the fuel fired. 2. In manufacturing, the average output of a process expressed as percent of

its expected output under ideal conditions. 3. The ratio of useful energy supplied by a dynamic system to the energy supplied to it over a given period of time.

- **ejector** A device which utilizes the kinetic energy in a jet of water or other fluid to remove a fluid or fluent material from tanks or hoppers.
- **elastomer** A material that can be stretched to approximately twice its original length with relatively low stress at room temperature, and which returns forcibly to about its original size and shape when the stretching force is released.
- **entropy** Function of the state of a thermodynamic system whose change in any differential reversible process is equal to the heat absorbed by the absolute temperature of the system. Also known as "thermal charge. "
- **explosion** Combustion which proceeds so rapidly that a high pressure is generated suddenly
- **Fission** (**Nuclear**) Process where the mass of an atomic nucleus is made smaller by the removal of subatomic particles. This process releases atomic energy in the form of heat and electromagnetic radiation.
- **Friction** Resistance between the contact surfaces of two bodies in motion.
- **Forging** mechanical forming of a metal or alloy by heating and hammering.
- **Fahrenheit** A temperature scale where the freezing point of pure water occurs at 32°F and the span between freezing point and boiling point of pure water at standard pressure is defined to be 180 scale divisions (180 degrees).
- **flammability** Susceptibility to combustion. flammable (explosive) limits The flammable (explosive) limits of a gas or vapour are the lower (LFL or LEL) and the upper (UFL or UEL) percentages by volume of concentration of gas in a gas-air mixture that will form an ignitable mixture.
- **fusible plug** A hollowed threaded plug having the hollowed portion filled with a low melting point material.
- **FLASH POINT** The lowest temperature under closely specified conditions at which a combustible material will give off sufficient vapor to form an inflammable mixture with air in a standardized vessel. Flash point tests are used to assess the volatilities of petroleum products.
- **Flaring** Burning off gas produced in association with oil which, for technical or economic reasons, cannot be re-injected or shipped ashore.
- **Gas** A state of matter where molecules are free to move in any direction they like. The state of matter where the substance completely fills any container that it occupies
- **Gravity** Is the process where anybody of mass found in the universe attracts other bodies with a force proportional to the product of their masses and inversely proportional to the distance that separates them.
- **gasket** A sealing member, usually made by stamping from a sheet of cork, rubber, metal or impregnated synthetic material and clamped between two essentially flat surfaces to prevent pressurized fluid from leaking through the crevice; typical applications include flanged joints in piping, head seals in a reciprocating engine or compressor, casing seals in a pump, or virtually anywhere a pressure tight joint is needed between stationary members. Also known as "static seal."
- **gland** 1. A device for preventing a pressurized fluid from leaking out of a casing at a machine joint, such as at a shaft penetration. Also known as "gland seal. " 2. A movable part that compresses the packing in a stuffing box.
- **governor** A device for automatically regulating the speed or power of a prime mover / engine .
- **HEADER** A common manifold in which a number of pipelines are united. Also used in reference to the U-bend connection between two consecutive tubes in a coil.
- **HYDROCARBON** A compound containing only hydrogen and carbon. The simplest hydrocarbons are gases at ordinary temperatures; but with increasing molecular weight, they change to the liquid form and, finally, to the solid state. They form the principal constituents of petroleum.
- **Hardenability** a measure of the depth to which a specific ferrous alloy may be hardened by the formation of martensite upon quenching from a temperature above the upper critical temperature.
- **Heat** Heat is defined as energy in the process of being transferred from one object to another because of the temperature difference between them. In the atmosphere, heat is commonly transferred by conduction, convection, advection, and radiation.
- **Homopolymer** a polymer having a chain structure in which all units are of the same type.
- **hydrocracker** A chemical reactor in which large hydrocarbon molecules are fractured in the presence of hydrogen.
- **hydrostatic test** Determining the burst resistance or leak tightness of a fluid component or system by imposing internal pressure.
- **Impact Energy** a measure of the energy absorbed during the fracture of a specimen of standard dimensions and geometry when subjected to very rapid (impact) loading. Charpy and Izod impact tests are used to measure this parameter, which is important in assessing the ductile-to-brittle transition behavior of a material.
- **Ideal Gas Law** This law describes the physical relationships that exist between pressure, temperature, volume, and density for gases. Two mathematical equations are commonly used to describe this law: Pressure x Volume = Constant x Temperature & Pressure = Density x Constant x Temperature
- **INERT GAS** Nitrogen on the refinery, scrubbed flue gas on the tankers. Used for air (oxygen) exclusion to reduce fire/explosion risk.
- **Ion** An atom, molecule or compound that carries either a positive (cation) or negative (anion) electrical charge.
- **induced draft** Airflow through a device such as a firebox or drying unit which is produced by placing a fan or suction jets in the exit duct.

- **intercooler** A heat exchanger in the path of fluid flow between stages of a compressor to cool the fluid and allow it to be further compressed at lower power demand.
- **interlock** 1. To arrange the control of machines or devices so that their operation is interdependent in order to assure their proper coordination. 2. Instrument, which will not allow one part of a process to function unless another part is functioning. 3. A device such as a switch that prevents a piece of equipment from operating when a hazard exists.
- **ion exchange** A chemical process for removing unwanted dissolved ions from water by inducing an ion exchange reaction (either cation or anion) as the water passes through a bed of special resin containing the substitute ion.
- **Joule** Unit for measuring energy. One joule is the energy used by a force of one Newton in moving its point of application in the direction of the force one meter.
- **kinematic viscosity** Absolute viscosity of a fluid divided by its density.
- **kinetic energy** 1. The energy of a working fluid caused by its motion. 2. Energy related to the fluid of dynamic pressure, 3. The energy due to motion.
- **KNOCKOUT (DRUM OR VESSEL)** A vessel, constructed with baffles, through which a mixture of gas and liquid is passed to disengage one from the other. As the mixture comes in contact with the baffles, the impact frees the gases and allows them to pass overhead; the heavier substance falls to the bottom of the drum.
- **Laser** **light amplification by stimulated emission of radiation**
- **Latent Heat** Is the energy required to change a substance to a higher state of matter (solid **>** liquid **>** gas). This same energy is released from the substance when the change of state is reversed (gas **>** liquid **>** solid). -Or –heat that does not cause a temperature change .
- **laminar flow** 1. A type of streamline flow most often observed in viscous fluids near solid boundaries, which is characterized by the tendency for fluid to remain in thin, parallel layers to maintain uniform velocity. 2. A nonturbulent flow regime in which the stream filaments glide along the pipe axially with essentially no transverse mixing. Also known as "viscous" or "streamline flow." 3. Flow under conditions in which forces due to viscosity are more significant than forces due to inertia.
- **light-emitting diode (LED)** A semiconductor diode which emits visible or infrared light. Light from an LED is incoherent spontaneous emission, as distinct from the coherent stimulated emission produced by diode lasers and other types of lasers.
- **Melting Point** the temperature at which a solid substance changes to a liquid state
- **Melting** The physical process of a solid becoming a liquid. For water, this process requires approximately 80 calories of heat energy for each gram converted.
- **MOLECULAR WEIGHT** The sum of the atomic weights of the atoms composing a molecule.
- **Natural Gas** Hydrocarbon based gas, mainly composed of methane, commonly found in the pores of sedimentary rocks of marine origin.
- **Neutron** Atomic sub-particle found in the nucleus of an atom. This particle is similar in mass to a proton but does not have an electromagnetic charge
- **Newton** A unit of force that creates an acceleration on a mass of 1 kilogram equal to 1 meter per second with no friction and under the conditions of a vacuum.
- **Nuclear Energy** Energy released when the nucleus of an atom experiences a nuclear reaction like the spontaneous emission of radioactivity, nuclear fission, or nuclear fusion.
- **natural draft** Convective flow of a gas as in a boiler, stack or cooling tower-due to differences in density. Warm gas in the chamber rises toward the outlet, drawing in colder, more dense gas through inlets near the bottom of the chamber.
- **neoprene** A synthetic rubber which exhibits excellent resistance to weathering, ozone, flames, various chemicals and oils.
- **orifice plate** A disc or plate like member, with a sharp edged hole in it, used in a pipe to measure flow or reduce static pressure.
- **PURGING** The removal of one fluid from a vessel or plant by introduction and subsequent evacuation of a second fluid. A common usage of this operation is in the removal of hydrocarbon vapours or air from a plant by flushing with nitrogen.
- **Poisson's Ratio** for elastic deformation, the negative ratio of lateral and axial strains that result from an applied axial stress.
- **Polymer** a solid, nonmetallic (normally organic) compound of high molecular weight the structure of which is composed of small repeat units.
- **pH:** Basically it is an indicator of whether a material is acidic in character or basic in character. It is a number ranging from 1 to 14. -From 1 to less than 7 , the material is acidic and from above 7 to 14, the material is basic and at 7.0, the material is neutral (neither acidic nor basic )
  -By definition, pH is negative log of Hydrogen ion concentration
- **Potential Energy** Is the energy that a body possesses by virtue of its position and that is potentially transformable into another form of energy.
- **parts per million (ppm)** Represents parts per million and should be given on a weight basis. The abbreviation shall be ppm (w/w). If inconvenient to present data on a weight bases (w/w), it may be given in a volume basis; (v/v) must be stated after the term ppm
- **pascal** Metric unit for pressure or stress.
- **piping and instrumentation drawing (P&ID)** 1. Show the interconnection of process equipment and the instrumentation used to control the process. In the process industry, a standard set of symbols is used to prepare drawings of processes. The instrument symbols used in drawings are generally based on Instrument Society of America (ISA) Standard S5. 1. 2. The primary schematic drawing used for laying out a process control installation.
- **pitot tube** 1. An instrument for measuring stagnation pressure of a flowing liquid; it consists of an open tube pointing upstream, into the flow of fluid, and connected to a pressure indicator or recorder. 2. An

instrument which will register total pressure and static pressure in a gas stream, used to determine its velocity.

- **pressure, gauge** 1. Pressure measured relative to ambient pressure. 2. The amount by which the total absolute pressure exceeds the ambient atmospheric pressure.
- **pressure, rupture** The pressure, determined by test, at which a device will burst. NOTE: This is an alternate to the design procedure for establishing maximum working pressure (MWP). The rupture pressure test consists of causing the device to burst.
- **pressure, static** The steady state pressure applied to a device; in the case of a differential pressure device, the process pressure applied equally to both connections.
- **Pressure,** in mechanics, ratio of the force acting on a surface to the area of the surface; it is thus distinct from the total force acting on a surface. A force can be applied to and sustained by a single point on a solid. However, a force can only be sustained by the surface of an enclosed fluid, i.e., a liquid or a gas. Thus it is more convenient to describe the forces acting on and within fluids in terms of pressure. Units of pressure are frequently force units divided by area units, e.g., pounds per square inch, dynes per square centimeter, or Newton (N) per square meter.
- **Random Copolymer** a polymer in which two different mer units are randomly distributed along the molecular chain
- **Radiation** The emission of energy from an object in the form of electromagnetic waves and photons.
- **reflux** The recycle stream that is returned to the top of the column. This stream supplies a liquid flow for the rectifying section that enriches the vapour stream moving up the column. Material in the stream is condensate from the overhead condenser. Reflux closes the energy balance by removing heat introduced at the reboiler.
- **relative humidity** 1. The ratio of the amount of water vapour contained in the air at a given temperature and pressure to the maximum amount it could contain at the same temperature and pressure under saturated conditions. 2. The ratio of the weight of water vapour present in a unit volume of gas to the maximum possible weight of water vapour in unit volume of the same gas at the same temperature and pressure.
- **relief valve (safety)** An automatic pressure relieving device actuated by the pressure upstream of the valve and characterised by opening pop action with further increase in lift with an increase in pressure over popping pressure.—OR-- A device used to protect piping and components from overpressure.
- **root mean square value (rms)** 1. A statistical averaging technique where all data are individually squared, the average of those squares taken and the square root of that average taken. 2. Equal to 0.707 times the peak.
- **rotameter** A variable area, constant head, indicating-type rate of flow volume meter in which fluid flows upward through a tapered tube, lifting a shaped plummet to a position where upward fluid force just balances the weight of the plummet.
- **rupture disc** A diaphragm designed to burst at a predetermined pressure differential. Symbol rupture disc device A non reclosing pressure relief device that relieves excessive static inlet pressure via a rupture disc.
- **REACTION** Any chemical change; the transformation of one or more molecules into other molecules.
- **Second Law of Thermodynamics** This law states that heat can never pass spontaneously from a colder to a hotter body. As a result of this fact, natural processes that involve energy transfer must have one direction, and all natural processes are irreversible. This law also predicts that the entropy of an isolated system always increases with time.
- **Sensible Heat** Heat that can be measured by a thermometer and thus sensed by humans.
- **Shear Stress** Stress caused by forces operating parallel to each other but in opposite directions.
- **Specific Heat** Is the heat capacity of a unit mass of a substance or heat needed to raise the temperature of 1 gram (g) of a substance 1 degree Celsius.
- **Spectrum** Is a graph that describes the quantity of radiation that is emitted from a body at particular wavelengths.
- **soft water** Water which contains little or no calcium or magnesium salts, or water from which scale forming impurities have been removed or reduced.
- **solenoid** A type of electromechanical operator in which reciprocal axial motion of a ferromagnetic core within an electromagnetic coil performs some mechanical function; common applications include opening or closing valves or electrical contacts.
- **solenoid valve** A shutoff valve whose position is determined by whether or not electric current is flowing through a coil surrounding a moving iron valve stem.
- **sparger** Liquid distribution device consisting of a length of piping or tubing with holes at spaced intervals along the length; used in spray columns, liquid- vapour contactors, and spray dryers.
- **specific gravity (SG)** The ratio of the density of a material to the density of the water at the same conditions. Specific gravity: Gf= liquid at flowing condition referred to water at 60°F; Gg= gas referred to air, both at STP.
- **specific heat (sp ht)** 1. The quantity of heat, expressed in Btu, required to raise the temperature of 1 lb of a substance 1°F. 2. The ratio of the thermal capacity of a substance to that of water. The specific heat at constant pressure of a gas is designated cp. The specific heat at constant volume of a gas is designated cv. The ratio of the two (cp/cv), is called the ratio of specific heats, k.
- **standard atmospheric pressure** A reference pressure approximately equal to the mean atmospheric pressure at sea level, because atmospheric pressure varies with elevation and is not constant with time, standard atmospheric pressure is defined arbitrarily as an absolute pressure of 14.695 psi, 30.0 in. of mercury or 760 mm Hg (using mercury of density 13.595 g/cm3).

- **standard pressure** 1. The arbitrarily selected atmospheric pressure of 1000 millibars to which adiabatic processes are referred for definitions of potential temperature, equivalent potential temperature, etc. 2. A pressure of 1 atmosphere (101.325 Newtons per square meter), to which measurements of quantities dependent on pressure, such as the volume of a gas, are often referred. Also known as "normal pressure."
- **standard volume** The volume of 1 mole of a gas at a pressure of 1 atmosphere and a temperature of 0°C.
- **static pressure** 1. The pressure of a fluid that is independent of the kinetic energy of the fluid. 2. Pressure exerted by a gas at rest, or pressure measured when the relative velocity between a moving stream and a pressure measuring device is zero.
- **steam tracing** An arrangement for heating a process line or instrument air line to keep liquids from freezing or condensing-often, a piece of pipe or tubing carrying live steam is simply run alongside or coiled around the line to be heated.
- **superheat** To raise the temperature of steam above its saturation temperature. The temperature in excess of its saturation temperature.
- **superheated steam** Steam at a higher temperature than its saturation temperature.
- **sweet crude** Crude petroleum containing very little sulfur.
- **sweet gas** Natural gas containing no hydrogen sulfide or mercaptans.
- **Thermodynamic Laws** Laws that describe the physical processes, relationships, and phenomena associated with heat.
- **Thermometer** Device used to measure temperature.
- **Third Law of Thermodynamics** This law states if all the thermal motion of molecules (kinetic energy) could be removed, a state called absolute zero would result and all energy would be randomly distributed.
- **thermal bulb** A device for measuring temperature in which the liquid in a bulb expands and contracts with changes in temperature, causing a Bourdon tube element to elastically deform, thereby moving a pointer in direct relation to the temperature at the bulb.
- **thermal conductivity** Heat flow per unit cross section per unit temperature gradient.
- **thermocouple** Two dissimilar wires joined together that generate a voltage proportional to temperature when their junction is heated.
- **thermowell** A thermowell is a pressure tight receptacle adapted to receive a temperature sensing element and provided with external threads, flanges or other means for pressure tight attachment to a vessel.
- **ton** 1. A weight measurement equal to 2,000 lb (avoirdupois), short ton; 2,240 lb (avoirdupois), long ton; or 1,000 kg, metric ton. 2. A unit of measurement for refrigerating capacity equal to 200 Btu/min, or about 3517 W; derived from the capacity equal to the rate of heat extraction needed to produce a short ton of ice having a latent heat of fusion of 144 Btu/lb from water at the same temperature in 24 hr.
- **tray** A horizontal plate in a distillation column that temporarily holds a pool of descending liquid until it flows into a vertical "downcomer" and onto the next tray. Each tray has openings to permit passage of ascending vapours.
- **TURNAROUND** Time necessary to clean and make repairs on refining equipment after a normal run. It is the elapsed time between drawing the fires ( shutting the unit down) and putting the unit onstream again.
- **U tube manometer** A device for measuring gauge pressure or differential pressure by means of a U shaped transparent tube partly filled with a liquid, commonly water; a small pressure above or below atmospheric is measured by connecting one leg of the U to the pressurised space and observing the height of liquid while the other leg is open to the atmosphere; a small differential pressure may be measured by connecting both legs to pressurised space for example, high and low pressure regions across an orifice or venturi.
- **Vacuum** (1) Space devoid of atoms or molecules. (2) Emptying of air
- **Velocity** The speed of movement of an object in one direction.
- **Viscosity** The amount of the resistance to flow in a fluid due to intermolecular friction.
- **Volume** The occupation of space in three dimensions. Measured in cubic units.
- **Vapor** - Gaseous substance which can be at least partly condensed by cooling or comp.
- **vapour pressure** 1. The pressure of a vapour corresponding to a given temperature at which the liquid and vapour are in equilibrium. vapour pressure increases with temperature. 2. The pressure (for a given temperature) at which a liquid is in equilibrium with its vapour. As a liquid is heated, its vapour pressure will increase until it equals the pressure above the liquid; at this point the liquid will begin to vapourise.
- **velocity head** The pressure, measured in height of fluid column, needed to create a fluid velocity.
- **venturi** A constriction in a pipe, tube or flume consisting of a tapered inlet, a short straight constricted throat and a gradually tapered outlet; fluid velocity is greater and pressure is lower in the throat area than in the main conduit upstream or downstream of the venturi; it can be used to measure flow rate, or to draw another fluid from a branch into the main fluid stream.
- **venturi meter** A type of flowmeter that measures flow rate by determining the pressure drop through a venturi constriction.
- **venturi tube** A primary differential pressure-producing device having a cone section approach to a throat and a longer cone discharge section. Used for high volume flow at low pressure loss.
- **viscometer** An instrument that measures the viscosity of a fluid.
- **wet bulb thermometer** A thermometer whose bulb is covered with a piece of fabric such as muslin or cambric that is saturated with water; it is most often used as an element in a psychrometer.
    - **Vents** : Are needed to let gas usually air in and out of service. Basically remove the air pocket from the line.

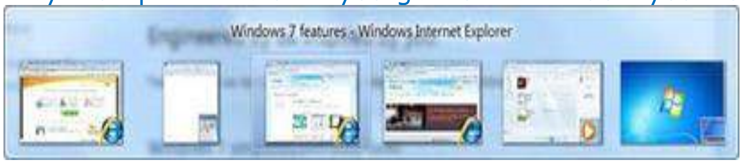
- **Break Flange** : Piping connected to channel head nozzle should be furnished with break flange to facilitate the removal of the channel head.
- **Temporary strainers** :Used for start – up operations on the suction side of pumps and compressors, after start – up the screen usually is removed.
- **Thermal Stresses :**Changes in temperature of piping due either to change in temperature of the environment or of the conveyed fluid cause changes in length of the piping
- **Condenser** : Condenses vapors by Transferring heat to cooling water, atmospheric air or other media.
- **Chiller** : Cools a process stream to very low temperature by evaporating a refrigerant.
- **Drums** : Collects liquids from vapors circuits and pump it to other process groups, disposal or product storage. Used in process plant as intermediate containers that received liquid from distillation and condensing equipment
- **Heat Exchanger** : The principal application of a heat exchanger is to maintain a heat balance through the addition or removal source or between stream of two different operating temperature.
- **Reactor** : Are used in processing facilities to contain catalyst that promote chemical reaction of feeds. Reactor are generally vertical steel hallow vessels and often operate under very high temperature and pressure.
- **Tower OR column** : Are cylindrical steel vessel that are used for distillation of materials in the production of such products as gasoline, diesel and heating oil.
- **Dry Steam** : Is a gas , consisting of water vapor only. Placed in contact with water at the same temperature, dry steam will not condense, nor will more steam form – liquid and vapor are in equilibrium.
- **Wet Steam** : Consists of water vapor and suspended water particles at the same temperature as the vapor. Heating ability (quality) varies with the percentage of dry steam in the mixture (The water particles contain to latent heat of vaporization) Like dry steam, Wet steam is in equilibrium with water at the same temperature.
- **Enthalpy of Water** It is the quantity of heat required to raise the temperature of one kg of water from 0**C** to its boiling point. It is depicted as **‘Hw’**
- **Latent Heat of Steam** Latent heat at a particular pressure of steam is defined as the quantity of heat in Kcal required to convert one kg of water at its boiling point into dry saturated steam at the same pressure It decreases with increase in pressure of the steam. It is depicted as ‘**λ**’
- **Enthalpy of Steam** Enthalpy of steam, in kcal, is defined as the quantity of heat required to convert one kg of water at 0**C** , at constant pressure into wet steam. It is depicted as **‘H’** Which can be written as **H= Hw + qL** --If steam is dry then **H= Hw + L**
- **Saturated Steam** When water is heated to generate steam, temperature of the steam will always be determined by the pressure. The steam, coming out from generating vessel at saturation temperature, which contain water particles with it, this steam is called **Saturated**

## 20 essential PC shortcuts:

- Copy a selected item: Ctrl+C
- Cut a selected item: Ctrl+X
- Paste a selected item: Ctrl+V
- Undo an action: Ctrl+Z
- Redo that thing I just undid: Ctrl+Y
- Select everything: Ctrl+A
- Print: Ctrl+P

### Switch between open windows

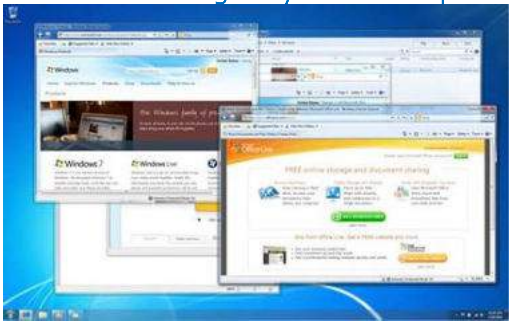
Alt+Tab If you have lots of open windows and you're not sure exactly which one you need, press Alt+Tab, and get a quick thumbnail view of all open windows. Then, while holding down the Alt key, press the Tab key multiple times until you get to the window you want.



Press Alt+Tab to switch between open windows

### Clear away everything and show the desktop

Windows logo key ⊞+D -Use this shortcut when you want to minimize a lot of open windows at once to check something on your desktop. Clutter-to-clean with two fingers.



A desktop before pressing Windows logo key+D

The same desktop after pressing Windows logo key+D

### Minimize the window

Windows logo key ⊞+Down Arrow

Minimizing a window is a surefire way to see what's underneath it. And it's fast to use the shortcut. If the window is maximized already (covering the entire screen) it'll go to "normal" size. And if it's normal size, it'll minimize entirely.

### Maximize the window

Windows logo key ⊞+Up Arrow

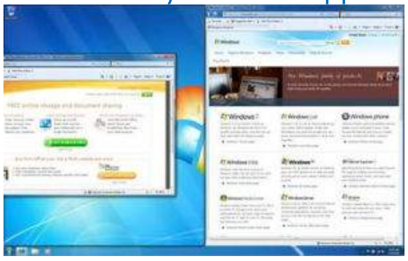
Maximizing windows works the same way.

Get even funkier with window management -It might surprise you to learn that there are even more options when it comes to dealing with your open windows and programs—but there are.

### Compare and contrast in a snap

Windows logo key ⊞+Left Arrow or Right Arrow

Snap is the easiest way I know to compare two documents—or to write up something while also looking at a web browser. The shortcut for Snap makes it even snappier. Go ahead and try this now. While pressing the Windows logo key ⊞, click the Right Arrow key or the Left Arrow key and your browser will slide over to one side. Select another window (such as a Word document) and use the shortcut only with the opposite arrow.



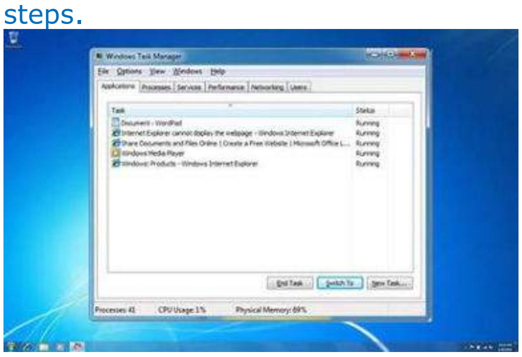
You can use a keyboard shortcut to view windows side-by-side with Snap

**Multitask with multiple monitors**

Windows logo key ⊞+Shift+Right Arrow or Left Arrow
Do you use more than one monitor at a time? Now you can shift an open window to your other monitor in less than a second.
Manage tasks -You might already be using a shortcut—Ctrl+Alt+Delete—to open up Task Manager or to lock your computer. But there are shortcuts for this shortcut.

**Open Task Manager**

Ctrl+Shift+Esc -This simple shortcut whisks you straight to Task Manager—without any intermediary steps.



| Task | Status |
|---|---|
| Document - WordPad | Running |
| Internet Explorer cannot display the webpage - Windows Internet Explorer | Running |
| Share Documents and Files Online \| Create a Free Website \| Microsoft Office L... | Running |
| Windows Media Player | Running |
| Windows Products - Windows Internet Explorer | Running |

Processes: 41 CPU Usage: 1% Physical Memory: 69%

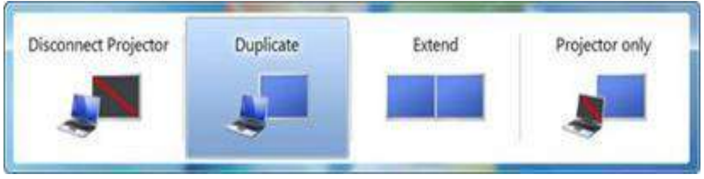
Task Manager in Windows 7

**Lock your PC or switch users**

Windows logo key ⊞+L -This shortcut locks your PC and instantly displays the login screen.
Display your way -No matter how you want to view your PC, shortcuts help you get there faster.

**Choose a presentation display mode**

Windows logo key ⊞+P



Whether you're giving a presentation or are using multiple monitors, it's simple to switch settings.
Choosing a presentation display mode

- **Zoom in, zoom out**
  Windows logo key ⊞+Plus Sign or Minus Sign ,The Plus Sign key (+) zooms you in, the Minus Sign key (-) zooms you out. This lets you see small text on a webpage or to check out the pixels in a photo.

You can use your keyboard to zoom in on a photo detail

**Search for files and folders**

Windows logo key ⊞+F -In the past, finding a file could be like an archaeology expedition. But nowadays, search is really fast and thorough. Use this shortcut to get a search window, type in a few keywords, and presto, you'll get your file.

**Open a new instance of a program**

Windows logo key ⊞+Shift+Click a taskbar icon ,I like Internet Explorer tabs—but sometimes I want a whole new browser window. To get one, I click the Internet Explorer icon while holding down Shift.

**And when you need it ...get help**

Windows logo key ⊞+F1 , It's the simplest shortcut out there. When all else fails, and you're just not sure what to do, press F1.

## ❖ HSE (Health, Safety, Environment )– SAFETY ASPECT

SAFETY FIRST
Safety Starts Here
Think Safe...
Work Safe...
Be Safe

### Types of Work Permits and Certificates

There are mainly **two types of work permits**: Hot Work Permit (HWP) and Cold Work Permit (CWP).

preparing a site for a task / job, it is necessary to issue WORK PERMIT depends upon nature of jobs and need to check following **types of certificates** depends on job / if required**:**

- Confined Space Entry Certificate (CSEC).
- Clearance for Excavation Certificate (CEC).
- Vehicle Use Certificate (VUC).
- Gas Testing Certificate (GTC)
- Safety Critical Bypass form / reference
- Isolation Confirmation Certificate (ICC).
- Lifting plan
- LOTO

| | |
|---|---|
| **Cold Work** | Any activity that is not a hot work but it has its own risk.<br>Some examples of cold work activities can be: working on the firefighting facilities or on safety critical elements, working on IT systems, inspection of equipment , housekeeping activities, pressure testing, working in confined spaces, spading / de-spading, general repairs, removal of collective protections at height, sampling , high pressure water jetting, non-flammable chemical cleaning, diving operations, removing insulation, painting, manual excavation with non-sparking tools, scaffolding activities, electrical isolation, installation of instrumentation (no live tie-ins), etc…. |
| **Confined Space Entry Certificate** | A form that must be issued when it is necessary to perform any job or to enter into a confined space. The CSEC allows to certify that the conditions inside the confined space allow to work and it also stipulates the level of precautions while work is being carried out.<br>The entry certificate does not permit any work to be carried out. The appropriate permit to work must be raised before any task can be undertaken.<br>The entry certificate also allows inspection by the Authorized Gas Tester to be done within the space |
| **Excavation Clearance Certificate** | A form that must be issued when it is necessary to any excavation deeper than 0.25 meters to ensure there are no any underground interference. |
| **Fire watcher** | A person trained on the use of fire extinguishers and the basics of fire to be present during hot work at processing areas for first intervention if needed. This person can belongs either to the contractor company executing the work or to a third subcontracted company. |
| **Gas Tester** | An authorized person to monitoring the working atmosphere / gas before start working and signing the work permit. |
| **Gas Testing Certificate** | A form that must be issued to perform any kind of gas testing (toxic, flammable, etc.), to be filled only by authorized gas tester. |
| **Hot Work** | Any activity that can be a source of ignition when flammable material is present or can be a fire hazard regardless of the presence of flammable material in the workplace.<br>Some examples of hot works can be: welding, soldering, (flame) cutting, grinding, brazing, use of combustion sources (heating, heat blowers, diesel generators, vehicles), use of electrical or electronic devices without certificate for working at classified areas (electrical soldering irons, hand-powered tools, camera, video camera, etc.), manipulation of electrical equipment (opening live junction boxes, electrical soldering), shot blasting, radiography tests, lifting activities (crane is a diesel engine), etc. |
| **ICC (Isolation Confirmation** | A form that must be issued before issuing the Work Permit when it is necessary to isolate the sources of energy (electricity, process fluids, |

| | |
|---|---|
| **Certificate)** | mechanical drive, instrumentation, others) to avoid any harm on the workers. The ICC ensures that the isolations are applied and documented in a through and systematic manner and it includes in one document a record of all the isolations required for the task and their status. ICC's are attached to the Work Permit form. No Work Permit can be issued if the ICC has not been previously issued and is available. |
| **Isolation Authority** | The person responsible of isolating the energy of any equipment before working on it. |
| **Issuing Authority** | in charge of the area where the work permit needs to be issued. This role can be held only by employees. |
| **Job Originator** | A person belonging to the department in charge of the work that needs to signs the work permit to explicitly authorize a Performing Authority to apply for the job using the Work Permit forms. |
| **LEL (Low Explosion Limit)** | The lowest concentration (percentage) of a gas or a vapor in air capable of producing a flash of fire in presence of an ignition source. |
| **Line break** | The opening of any pipe, vessel or processing equipment which has the risk of releasing any type of internal energy to the worker. |
| **LOTO** | Lock Out – Tag Out, which is a system to release any energy (mechanical, chemical, electrical, others) from any equipment before working on it. |
| **Performing Authority** | in charge of the job on a continuous basis who is present on the site during the work. This person can be member of the company. |
| **Vehicle Use Certificate** | A form that must be issued when it is necessary for personnel to use vehicles in the operational restricted areas to carry out work |
| **VOC (Volatile Organic Compounds)** | Hydrocarbon compounds that have low boiling points, evaporate readily.<br>• When it is related to VOCs, the criteria to be used will be as follows:<br>○ Total VOC gas testing shall be done.<br>○ Benzene gas testing with specific instrument shall be done.<br>○ If tests confirms that Benzene is present, decision shall be taken based on this contaminant by applying the guideline.<br>○ If Benzene is not present, it will be taken a TWA of 5 ppm as a reference (by considering the second worst case scenario of having mainly diethyl-benzenes compounds). In this case, the following decisions shall be taken:<br>▪ If measured [VOC] is higher than 5,000 ppm, SCBA.<br>▪ If measured [VOC] is higher than 125 ppm, Supplied Air Respirator or SCBA.<br>▪ If measured [VOC] is lower than 125 ppm but there is oil mist above 0.1 mg/m$^3$, full face mask with appropriate cartridges R- or P- 3M series shall be used (to be advised by HSE).<br>• When it is related to mercaptans, the criteria to be used is as follows:<br>○ Mercaptans gas testing shall be done by specific gas detector<br>▪ If measured [mercaptans] is higher than 100 ppm, SCBA or Supplied Air Respirator shall be required.<br>▪ If measured [mercaptans] is lower than 100 ppm full face mask with appropriate cartridges R- or P- 3M series shall be used (to be advised by HSE). The use of full face mask for such cases will be assessed by HSE and it will consider multiple factors: workers without barb to ensure proper adjustment, positive and negative tests once the masks are in place, etc. |
| **MS /RA** | **MS** – Method of work statement / job , **RA** – Risk Assessment of job |
| **Lifting plan** | lifting plan for proper & safe lifting purpose |

**Authorized levels for working based on the measured conditions are summarized in the following table**

| Parameter | Measured concentration | Type of work | Decision |
|---|---|---|---|
| **LEL** | ≤ 1% | All works | Allow start working |
| | 1 < LEL ≤20% | Limited type of hot works in open areas | Allow start working with continuous gas monitoring EXCEPT open flame works and highly sparking works (grinding, brushing, etc.). Local inertisation required |
| | | Any hot work in confined spaces | Not allowed. Work cannot start or needs to be cancelled. |
| | > 20% | All works | Not allowed. Specific measures to be applied under Method of Statement/Risk Assessment. |
| **OXYGEN** | ≤ 20.5% | All works | Works allowed only using SCBA (scape masks are not allowed for working purposes). Risk Assessment is required). |
| | 20.5% ≤ $O_2$ ≤ 21.5 % | All works | Allowed |
| | 21.5% < $O_2$ ≤ 23.5 % | Hot Works | Not allowed |
| | | Cold Works | Cold works allowed with special precautions, to be determined for each case with HSE Officer. |
| | > 23.5% | All works | Not allowed |
| **$H_2S$** | > 0 ppm and 0% LEL | All works | Only using SCBA. |
| | > 0 ppm and ≤ 10% LEL | Hot works in open areas | Allow start working with continuous gas monitoring, use of SCBA EXCEPT open flame works and highly sparking works (grinding, brushing, etc.). |
| | | Hot works in confined spaces | Not allowed |
| | > 0 ppm and > 10% LEL | All works | Not allowed |

Go Home Safe Today!
Others Are Depending On You!

**"Watch your thoughts, they become words; watch your words, they become actions; watch your actions, they become habits; watch your habits, they become character; watch your character, for it becomes your destiny."**

With my best wishes ……….regard and respect to all.

PANKAJ. PATEL .